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ORIGINAL

Selected Developments in Laser Wire Stripping

39

NASA SP-5107

Selected Developments in Laser Wire Stripping

November 1977

Technology Utilization Division 1977
National Aeronautics and Space Administration
Washington, DC

FOREWORD

The National Aeronautics and Space Administration has established a Technology Utilization Program for the rapid dissemination of information on technological developments that have potential utility outside the aerospace community. To assure the greatest possible benefits to the public from the space program, emerging technology and innovations are continuously screened and those having potential industrial or educational use are presented in a series of NASA publications. This report is one of a series of such publications sponsored by the NASA Technology Utilization Division to help industry and institutions benefit from research and development in the aerospace field.

INTRODUCTION

This book is intended to stimulate and facilitate further advances in laser wire stripping. To that end it describes equipment and techniques developed recently to utilize lasers to cut and strip insulation from wires and cables. Because a focused laser beam will reflect harmlessly from an underlying metallic conductor while vaporizing a narrow slit in wire insulation, it is the only presently known means for rapidly stripping aerospace-type wire with no risk of nicking or scraping the conductor.

The first two chapters review the operation of mechanical and thermal strippers and the early development of laser wire strippers.

The remaining two chapters detail the NASA-sponsored development of laser wire stripping for use on Space Shuttle wire assembly. Bench-type strippers have been developed, but an advanced portable hand-held stripper for Shuttle production has been a major development. It incorporates a miniaturized carbon dioxide (CO_2) laser and a rotating optics unit with a gas-jet assist and debris exhaust, and includes drives and controls to girdle the wire and slit the remaining slug without manual assistance. This unit can strip wire sizes 26 through 12 gage. A larger-capacity hand-held unit for wire sizes through 1/0 gage has been built using a neodymium-doped yttrium aluminum garnet (Nd:YAG) laser. The hand-held units have a flexible umbilical cable to an accompanying cart that carries the power supply, gas supply, cooling unit, and the controls.

ACKNOWLEDGMENTS

The technology and innovations described were developed by Messrs. Robert M. Heisman, William F. Iceland, Andrew R. Keir, Lester A. Small, and Floyd R. Yerian of Rockwell International Corp., Downey, California under contract to Johnson Space Center, Houston, Texas.

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CHAPTER 1
RATIONALE OF LASER WIRE STRIPPING

A laser beam can cut through the insulation on a wire without damaging the conductor, because the laser radiation that melts the insulation is merely reflected by the metal. Therefore, a wire stripper that uses a laser beam eliminates the quality-control problems of nicked and cut wires; moreover, the process is fast, clean, precise, and repeatable.

Laser Stripping vs. Conventional Strippers for Aerospace

The feasibility of wire stripping by lasers is extremely important to the aerospace industry. To reduce the weight of components in aircraft and space vehicles, the industry has adopted electrical wiring with light plastic types of insulation, such as polyimide film (Kapton, H-Film), nylon, Teflon, and PVC. The use of these materials has reduced the weight of a space vehicle by several hundred pounds, but they are more difficult to strip with conventional wire strippers.

Some of the plastic films on the latest aircraft/aerospace-grade wire are so thin (a few mils) and tough that it is difficult to center mechanical cutters with the precision required to avoid cutting or nicking some of the wire strands—which is unacceptable under the rigid standards that apply to the aerospace industry.

Mechanical hand strippers, including the typical tool shown in Figure 1, have been modified by providing higher precision cutters and improved grips to permit normal stripping of new thin insulations without nicking or scraping the conductors or damaging the insulation by the increased grip pressure required. With operator training and inspection surveillance, the possibility of wire damage by these mechanical strippers can be minimized, but the positive assurance of the laser stripping method cannot be achieved.

The danger of wire damage is eliminated by the use of a thermal wire stripper (Figure 2), but such devices are slow and require frequent calibration. Thermal hand wire strippers using electrically heated elements cut the insulation by melting. The heating elements in the average unit are rated at about 300 watts. The increased temperature resistance of many new aerospace insulation materials has made thermal stripping more difficult. The melted cuts are quite wide and the material tends to adhere to the conductors. Close adjustment of the temperature and position of the elements is required. The time required to peripherally cut is about one minute. Some thermal strippers also slit the remaining slug for easy removal and this increases the stripping time.

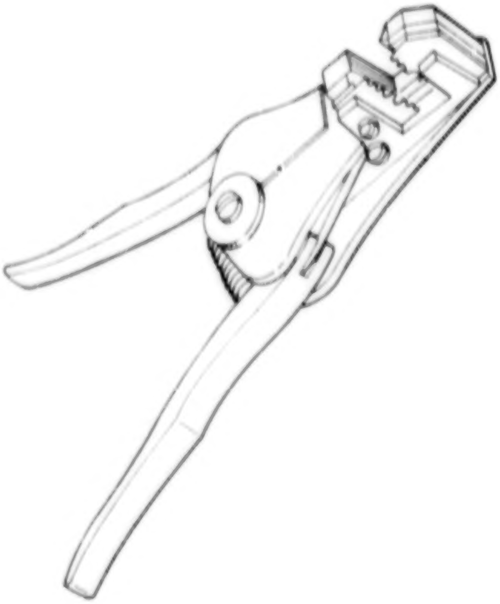


Figure 1. *Mechanical stripper* is fast, but it requires precision calibration to remove tough, thin Kapton insulation (or equivalent) from a wire without nicking or scraping the conductors.

Therefore, NASA and aerospace contractors have considered the use of laser wire strippers. Prototype devices have been tested and reliable production-type laser wire strippers have been built for Shuttle high-volume wire assembly. American Wire Gage No. 1/0 wire, which has approximately 1100 strands of conductor, can be stripped without damage to a single strand. Wire strippers can be built to handle larger or smaller wire. Present limits were the requirements for the Shuttle Orbiter.

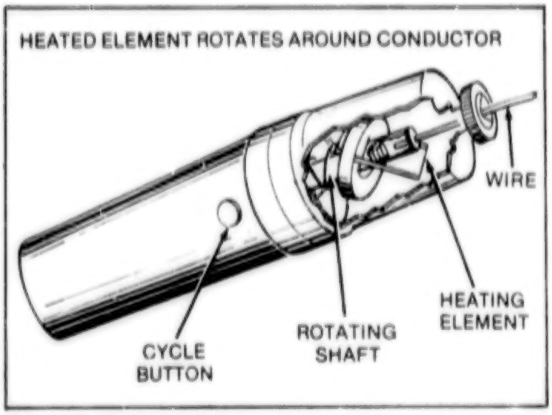


Figure 2. ***Thermal stripper*** **does not damage the conductors while stripping the insulation from a wire, but it is slow and requires frequent calibration to cut satisfactorily.**

NASA's Role in Laser Wire Stripping

NASA has sponsored the development of laser wire strippers for production use in its Space Shuttle program. These tools are specifically designed for stripping the Kapton-insulated wire (or equivalent), MIL-S-81318, used in the Shuttle Orbiter. Both bench-mounted and hand-held units have been developed for stripping wire sizes from American Wire Gage (AWG) No. 26 to No. 1/0. Figure 3 shows Kapton insulation being cut from a wire by an early experimental unit using a laboratory carbon dioxide (CO_2) laser. This work led to the development of minimum-power small units. Figure 4 shows the clean wire strip now being achieved. The advantages of the laser wire stripper are summarized in Table 1.

NASA work in the field has included development of more compact and shorter focal-length rotating optics to provide faster stripping at lower power in portable units; incorporation of gas-jet assist to prevent lens dirtying and provide faster, cleaner cutting; and the use of fiber optics with yttrium aluminum garnet (YAG) laser strippers. NASA also developed both CO_2 and YAG small hand-held laser strippers having flexible supply connections to portable wheeled supporting carts carrying the supporting supply and control units for use in wire assembly areas. Further details and descriptions of other accessory development are presented in Chapters 3 and 4.

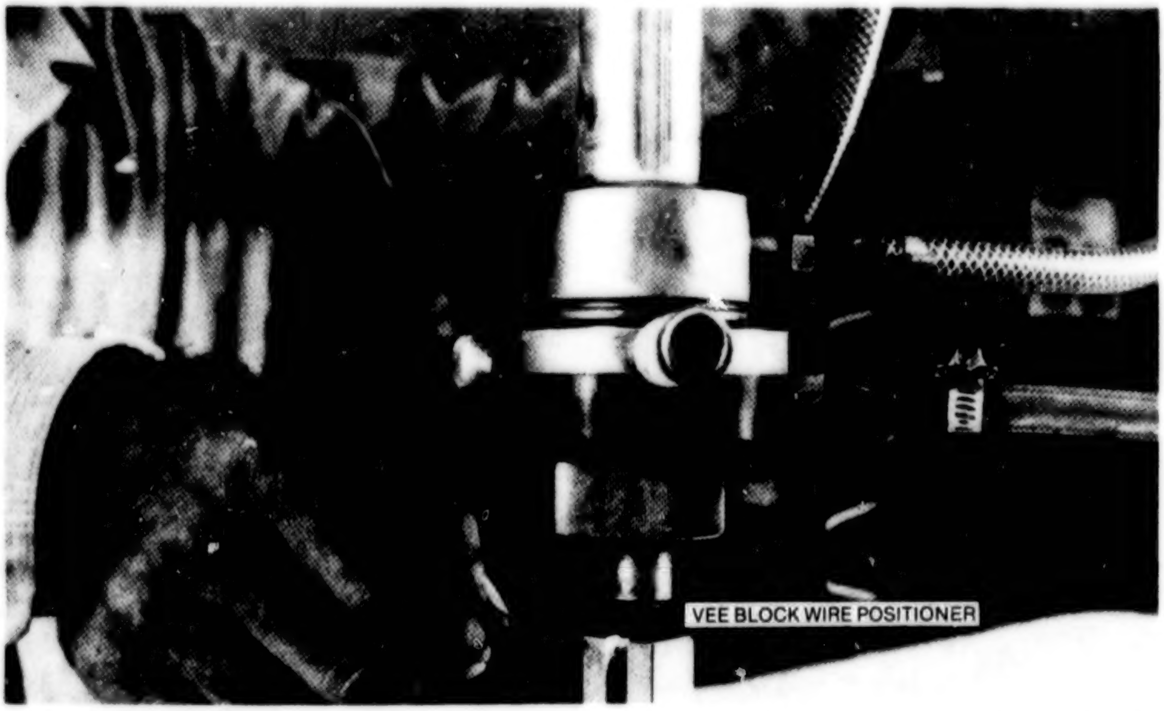


Figure 3. This early ***Experimental laser stripper*** **required manual rotation of the wire end on a vee block. A modified 250-watt laboratory CO_2 laser was used for tests at various power levels and gas assist combinations with different types of wire. For later rotating optic units, see Figures 12 and 15. An interim wire-rotating device is shown in Figures 8 and 9.**

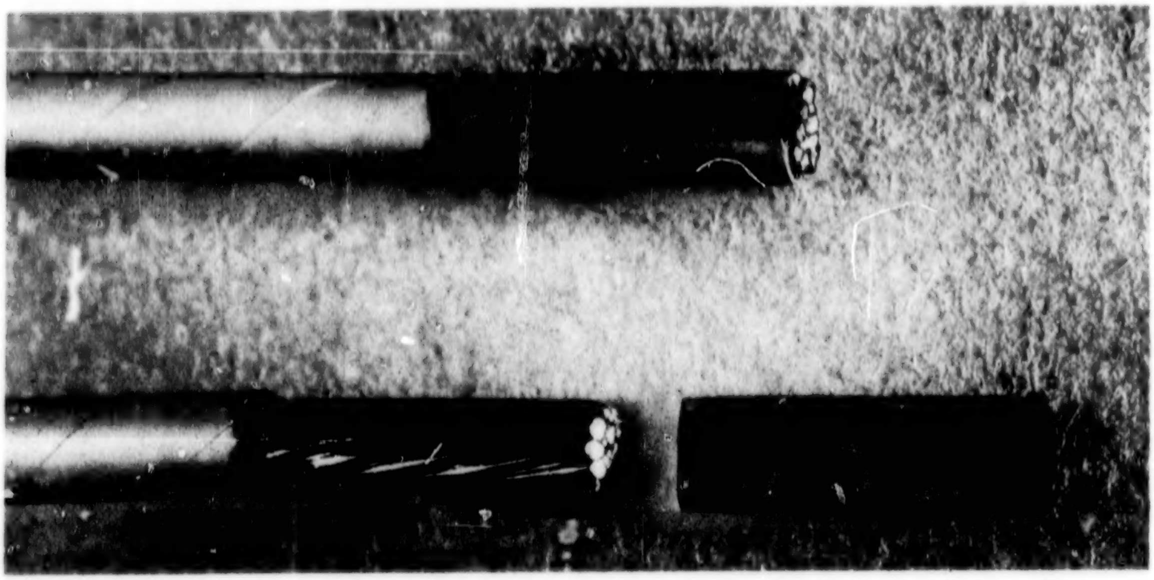


Figure 4. This Kapton-insulated 18-gage (MIL-S-81381) aircraft-grade stranded wire was stripped on the experimental laser wire stripper in Figure 3. The slit along the wire end (slug) was made as the wire was withdrawn. The slit slug is easily removed as shown. Wire sizes from AWG-26 through 1/0 were used for extensive testing.

The Mechanism of Laser Stripping

The laser beam cuts insulation by the process of ablation—i.e., by melting and vaporization; this mechanism requires absorption of roughly 100 kW/in.[2] at the surface of the insulation. The power required is minimized by reducing the area of beam focus on the wire and controlling other variables. The power density in the focused laser spot can be estimated from:

$$\text{power density} = PD^2/8\lambda^2 f^2$$

where power density is expressed in kilowatts per square inch, P is the output from the laser in watts, D is the laser-beam diameter in inches, λ is the wavelength of the laser radiation in micrometers, and f is the focal length of the focusing lens in inches. For high power density, a short wavelength is favored; however, in some cases the short waves may be reflected from instead of absorbed by the insulation, so a longer wavelength can often prove to be more effective.

Various designs of laser wire strippers are discussed in the subsequent chapters. The particular designs represent the growth of experience with the technology, restraints on the availability of laser types and their intended uses, and the properties of the wire to be stripped. For example, Teflon absorbs the 10.6-μm radiation from a CO_2 laser, but reflects the 1.06-μm beam from a YAG laser.

Table 1. Advantages of Laser Wire Stripping
Elimination of direct mechanical contact with wire
Narrow width of melted or vaporized zone
High-temperature insulation easily stripped
Rapid stripping time (less than 1.5 seconds)
Conductor metallurgy not affected by laser beam
Quality-control requirements minimized

CHAPTER 2
DEVELOPMENT OF LASER WIRE STRIPPING

Laser wire stripping was tested almost as soon as lasers with sufficient power became available. Some of the earlier work was done by IBM Corp. (references 1 and 2), using a CO_2 laser to notch the insulation around the circumference of a wire rotating in the laser beam. If the cut was near the end of the wire, the insulation could then be slipped off. The same cutting technique was also used to remove insulation from the middle of multistranded wires without untwisting the strands. This laser application was preceded by an earlier approach (reference 2) that stripped the insulation from fine wire by firing a high-energy arc across a gap containing the wire. The arc plasma vaporized the insulation, leaving a sharp insulation edge.

A laser stripper system developed by the Martin Marietta Corp. used a rotatable optical unit (references 3 and 4). As shown in Figure 5, the beam from a CO_2 laser was focused at right angles to a nonrotating wire inserted along the central axis of the rotary stripping head. Rotation of the optical unit produced a circumferential cut in the insulation. The unit could also be used in a nonrotating mode to slice the insulation longitudinally as the wire was withdrawn. This system was built for in-plant use in missile-wiring production lines, and it is further described in a patent issued to Martin Marietta Corp. (reference 4).

While this work was in progress, NASA was pursuing its development of wire strippers predominantly in cooperation with Rockwell International Corp. Both bench-mounted and hand-held CO_2 laser wire strippers were developed. The application of Nd:YAG lasers using flexible fiber-optic transmission cables was also explored (references 5 through 7). The CO_2 laser beam (10.6-μm wavelength) provides the most efficient stripping action but can not be transmitted through flexible fiber optics, so the beam must be directed into the stripper by a reflecting system. The Nd:YAG laser beam (1.06-μm wavelength) will vaporize many insulation materials, including polyimide, but is not satisfactory for Teflon-type materials; however, this beam can be transmitted efficiently with special fiber optics.

Based on developmental experience with a modified 250-watt laboratory laser, a CO_2 production-type stripper for wire sizes 26 through 10 gage using a miniaturized hand-held 2.5-watt laser and a Nd:YAG unit using a 10-watt larger cart-mounted laser for wire sizes 26 through 1/0 gage have been built for Shuttle production use. They incorporate an oxygen gas assist and provide rapid stripping, including a slit slug using an improved rotating optics unit. Power supply, gas supply, exhaust, and cooling units, along with the control console, are mounted on an accompanying portable cart with flexible connection to the stripper. These developments are discussed in detail in Chapters 3 and 4.

Other concurrent developmental work was performed by the American Optical Corp., which announced an industrial cable-stripping laser system (reference 8). This system used a CO_2 laser to remove insulation from both sides of a flat bus cable simultaneously. However, it could not accommodate the standard type of wiring normally used in the aerospace industry.

More recently, the Bendix Corp. has investigated laser stripping for the removal of insulation from woven-wire tape and for wire breakage diagnosis (references 9 and 10). A CO_2 laser removed a two-layer polyester insulation from selected areas of a 90-strand AWG 33 multiconductor woven-wire tape quickly and cleanly without damage to the conductors.

In addition to the organizations that have conducted development programs on laser wire stripping, many other aerospace, electronics, and communications firms have expressed interest in obtaining data and/or equipment for evaluation of the technique for their particular applications.

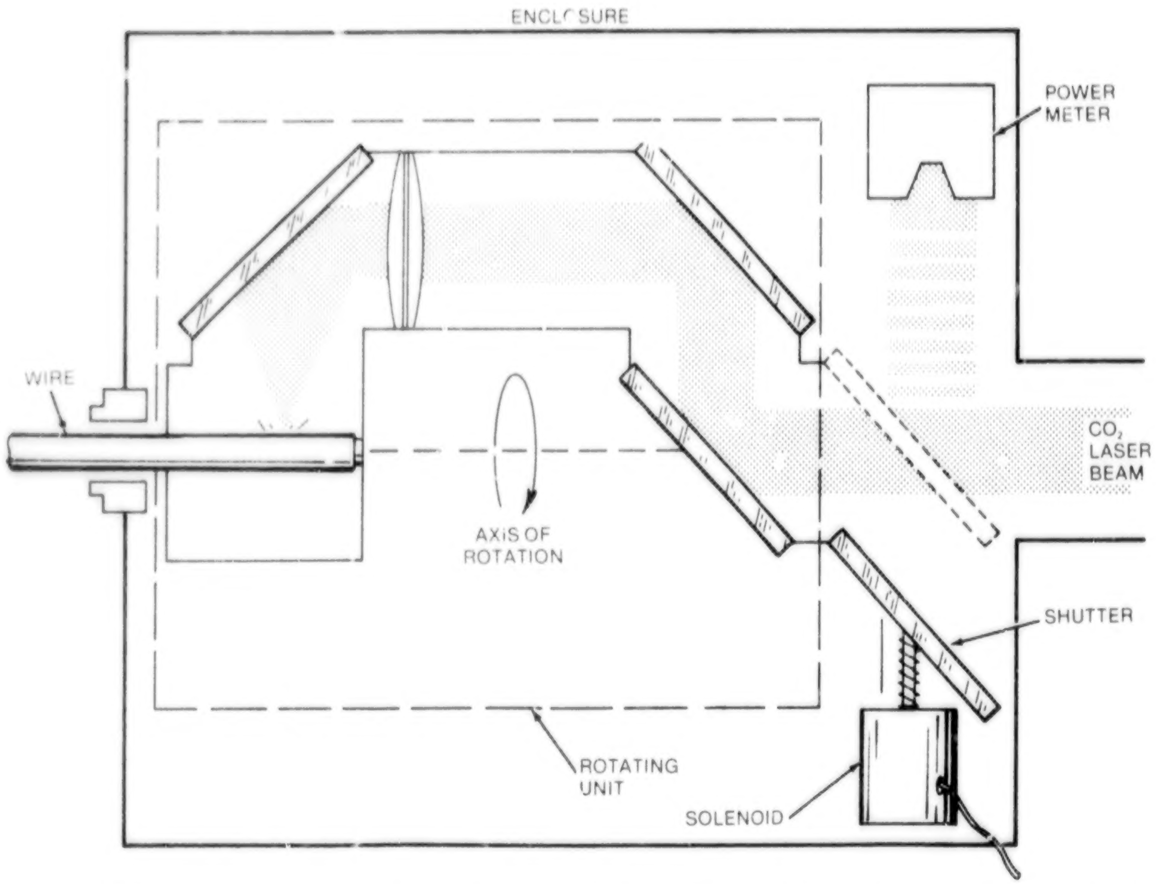


Figure 5. *Rotating optics laser wire stripper* developed by Martin Marietta Corp. utilizes a rotating assembly of three mirrors to direct a focused laser beam at right angles to the insulated wire. Another mirror, outside of the rotating unit, acts as a solenoid-controlled shutter to deflect the laser beam into a power meter for monitoring and calibration. (U.S. Patent No. 3, 953,706)

CHAPTER 3
NASA CONTRIBUTIONS TO LASER WIRE STRIPPING

NASA sponsored the development of laser wire strippers for use in the production of the Space Shuttle. After considering mechanical strippers (which often nicked or cut strands of the wire) and thermal strippers (which produced considerable charring, and left an insulation slug that was difficult to remove from the wire), NASA selected laser stripping as the best available method for providing defect-free stripped wire ends in high-volume production. Both bench-type and hand-held models were built to strip the Kapton-insulated wire (or equivalent), MIL-S-81381, specified for general-purpose interconnecting wiring in the Shuttle Orbiter.

Developing the System

Establishing the Concept

The concept of the NASA gas-jet-assisted laser wire stripper (reference 5) is illustrated in Figures 6 and 21. The laser beam is focused by a short-focal-length converging lens installed after the final rotating mirror to obtain minimum focal length to concentrate the light in the smallest possible spot on the insulation of the wire. High power density at the focal point is necessary to cut the insulation rapidly by melting, vaporizing, and burning. The conductor is not affected because it reflects the beam.

To maintain the wire-stripping process with minimum residual deposits on the optics and the stripped wire, the debris from the melted insulator must be removed. To accomplish this, the NASA system is designed with a gas plenum chamber enclosing the lens and having a nozzle opening combined with the laser-beam exit. The gas is supplied through a rotary connection to the housing of the rotating optics. The gas flow keeps debris from forming on the lens and the exit gas expels the molten reaction products. When oxygen is used, it provides an additional exothermic, or burning, action. An exhaust system attached to the stripper housing removes the vapors and debris produced during the stripping.

The wire is rotated one full turn to produce a full circumferential cut; then it is automatically moved longitudinally to slit the remaining insulation slug for easy removal. Figure 7 shows two

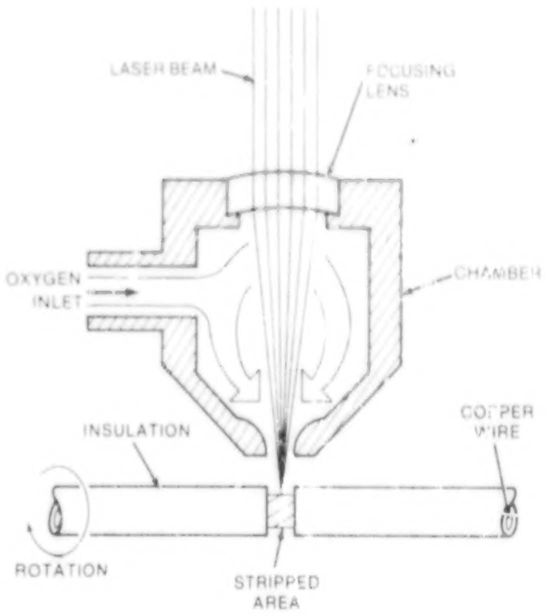


Figure 6. ***Focused laser beam strips insulation from wire.*** **The concentrated beam power (on the order of 10^5 W/in.^{2}) is absorbed by the insulation, which immediately melts, burns, vaporizes, and/or ablates. The conductor reflects the radiant energy of the laser beam, and therefore is not affected. A jet of oxygen assists in the stripping and also cools the lens and protects it from contamination.**

laser-stripped wires. The cut insulation (slug) is still in place on the upper wire, but has been peeled off of the lower one.

The developmental version of the bench model of the CO_2 laser wire stripper is shown in Figure 8. It used a 250-watt continuous output rated CO_2 laser that was modified to adjustably deliver from 1 to 15 watts of power in a 0.28-in.-diameter beam. It was mounted horizontally, as seen in the top of the photograph. A mirror angled at 45° deflected the output beam vertically downward through the converging lens and gas chamber onto the wire in a focused spot. The wire was held in a chuck that was rotated one revolution for peripheral cutting and moved longitudinally to slit the slug by geared dc permanent-magnet motors. For the later production-type unit using this laser with rotating optics, see Figure 12.

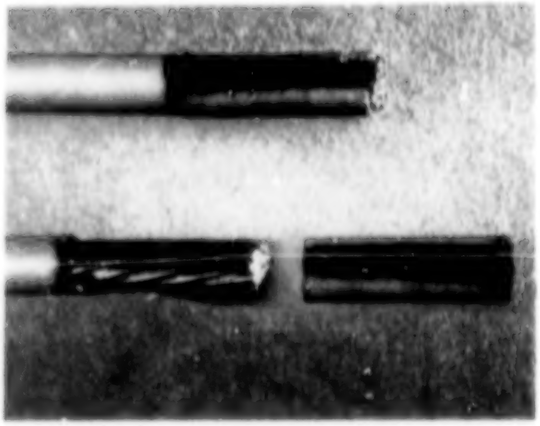


Figure 7. ***Circumferential and longitudinal*** **cuts made by the laser beam allow the insulation slug to be pulled off of the wire easily. The laser wire stripper makes the two cuts in 1.5 seconds.**

A closer view of the developmental electromechanical motion-control unit is shown in Figure 9. The geared dc motors, complete with integral feedback generators, were used in conjunction with dc amplifiers to form velocity-control systems designed for a 50-to-1 speed range. The maximum rotational speed was 4 revolutions per second or 240 revolutions per minute. The chuck was rotated by an O-ring belt. The gain-feedback of the system was adjusted for critical damping (fast response without oscillation). The maximum speed of longitudinal motion was 30 in./min. The wire-holding fixture was mounted on a high-efficiency ball-drive screw mechanism that drove it longitudinally. These experimental features proved feasible for use in the final production design.

In production versions of both the bench-type and hand-held units, the motion controls were revised to hold the wire fixed in a rotating optics system. This arrangement is discussed in detail later in this chapter.

Determining System Parameters

The laser power level required to achieve quality laser stripping at production rates competitive with conventional mechanical wire strippers was determined by extensive developmental tests. The selected target was to strip a wire in 1 to 1.5 seconds. Design was based on the following analysis.

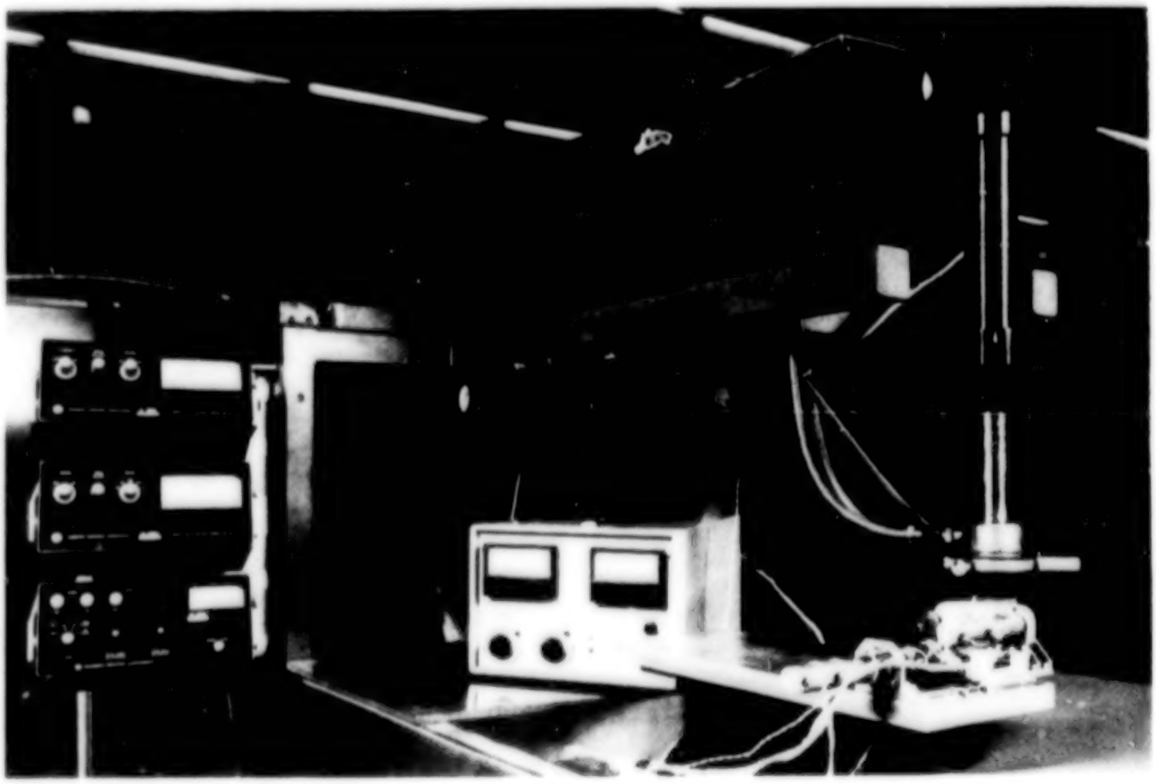


Figure 8. ***Experimental laser wire stripper*** **uses a 250-watt cw CO_2 laser modified to generate a beam with 1 to 15 watts of 10.6-μm radiation. Stationary beam is focused onto moving wire in motion-control unit at lower right.**

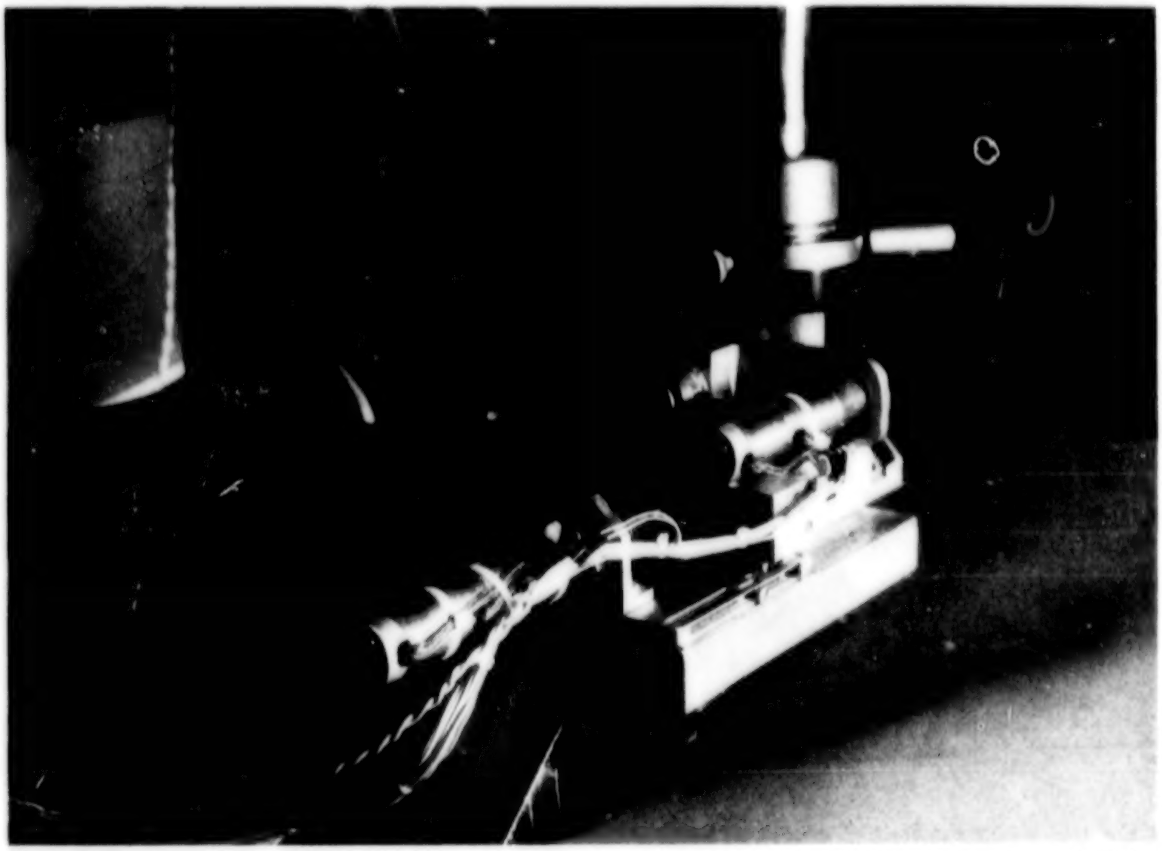


Figure 9. ***Electromechanical motion-control unit*, used in experimental laser wire stripper, grips wire in collet that is rotated and moved longitudinally by servocontrolled dc motors. In later models, the laser beam moves while the wire remains fixed (see Figure 11).**

The stripping rate is determined by the power density focused on the insulation, i.e., by the beam power and the spot size. The spot diameter is given by the formula

$$s = \lambda f/10D$$

where s is the spot diameter in mils, λ is the laser wavelength in micrometers, f is the focal length of the converging lens in inches, and D is the diameter of the laser beam in inches. Using a parallel beam from a CO_2 laser ($\lambda = 10.6\ \mu m$, $D = 0.28$ in.), lenses with focal lengths of 1.5, 2.5, and 5 in. produce spot diameters of 6, 10, and 20 mils, respectively. This illustrates the need for a short-focal-length lens to produce a small spot diameter.

The time required to strip insulation from wires of three sizes was measured with various laser power levels, lens focal lengths, and types of gas. The wire sizes used were American Wire Gage (AWG) Nos. 14, 18, and 24; the length of Kapton stripped off in each case was 3/16 in., which conformed to lugging and crimping requirements for Shuttle production. Table 2 summarizes the results of the tests. At the 1-watt level, the minimum time required to perform the stripping action was 2.58 seconds, which exceeds the design target time interval. Satisfactory stripping time under 1.5 seconds was achieved by both 1.5- and 2.5-in. focal-length lenses at the 3-watt level. Increasing the laser power increased the laser stripping speed linearly.

Experimentation with the gas-jet assist showed that changing from oxygen to argon or compressed air for the gas jet proved unsatisfactory below 3-watts (stripping time increased). The stripping action was inconsistent under an argon jet.

Table 2. Total Wire-Stripping Time							
Total time required (seconds) for one revolution plus 3/16-in. longitudinal travel							
Laser Power (watts)	1.5-in. F.L. Oxygen AWG No. 18	2.5-in. F.L. Oxygen AWG No. 18	5.0-in. F.L. Oxygen AWG No. 18	1.5-in. F.L. Argon AWG No. 18	1.5-in. F.L. Air AWG No. 14	1.5-in. F.L. Oxygen AWG No. 24	1.5-in. F.L. Oxygen AWG No. 14
1	2.58	4.25	10.63	**	31.25	13.25	*
2	1.46	*	*	**	8.5	3.85	1.66
3	1.16	1.58	2.4	*	1.29	1.55	0.89
4	0.99	1.21	1.46	1.04	*	1.5	0.5
5	*	*	*	0.73	*	*	*

* Data not available
** Stripping inconsistent below 3 W.
F.L. = focal length

At the 4-watt level, all combinations listed in Table 2 were acceptable. A 3-watt power level was initially selected as the minimum power level to produce clean rapid stripping with the least vapor deposition. Improved focusing has permitted reduction to 2.5 watts on the conductor in later units. Laser-beam power of 3-watts, using a 1.5-in. focal-length lens, with a 0.28-in.-diameter beam and 0.005 spot diameter, and oxygen as the gas-jet assist, were selected as design parameters. The power density in the focused spot with this arrangement is 10^5 W/in.^{2}.

Effect on the Conductor

The microstructure of nickel-coated copper wire was examined where the insulation had been removed by the laser and in an area unaffected by heat from the laser. No significant structural change could be detected under a magnification of 200 diameters.

In addition to the metallographic examination, a microhardness traverse was made along the length of the wire specimen through the heated area and into the unheated area. The hardness was measured on a Kentron microhardness tester using a Knoop indenter and applying a load of 50 grams. The readings were taken at 0.005-in. intervals for a total length of 0.200 in. The average Knoop (50-gram load) hardness number was 68, with one low reading of 37 and a high of 100. These readings were attributed to normal variations expected in a traverse of this type, and it was concluded that the microhardness examination had detected no appreciable effect from the laser removal of insulation.

Figure 10 is a photomicrograph of the heated and unheated zones. The magnification is 200 diameters; a potassium dichromate etchant was used to define the grain structure.

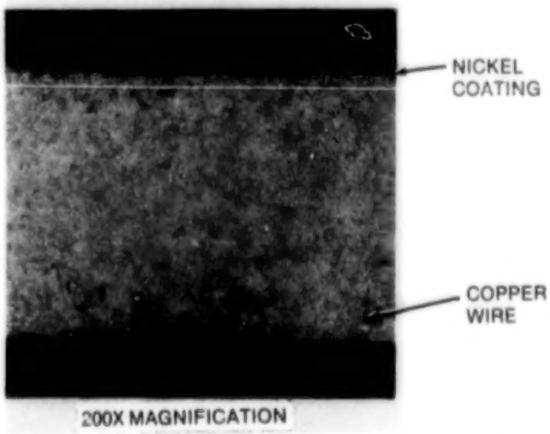


Figure 10. *Microphotograph* of an etched wire section show that the conductor grain structure is unaffected by the heat of the laser beam that stripped off the insulation.

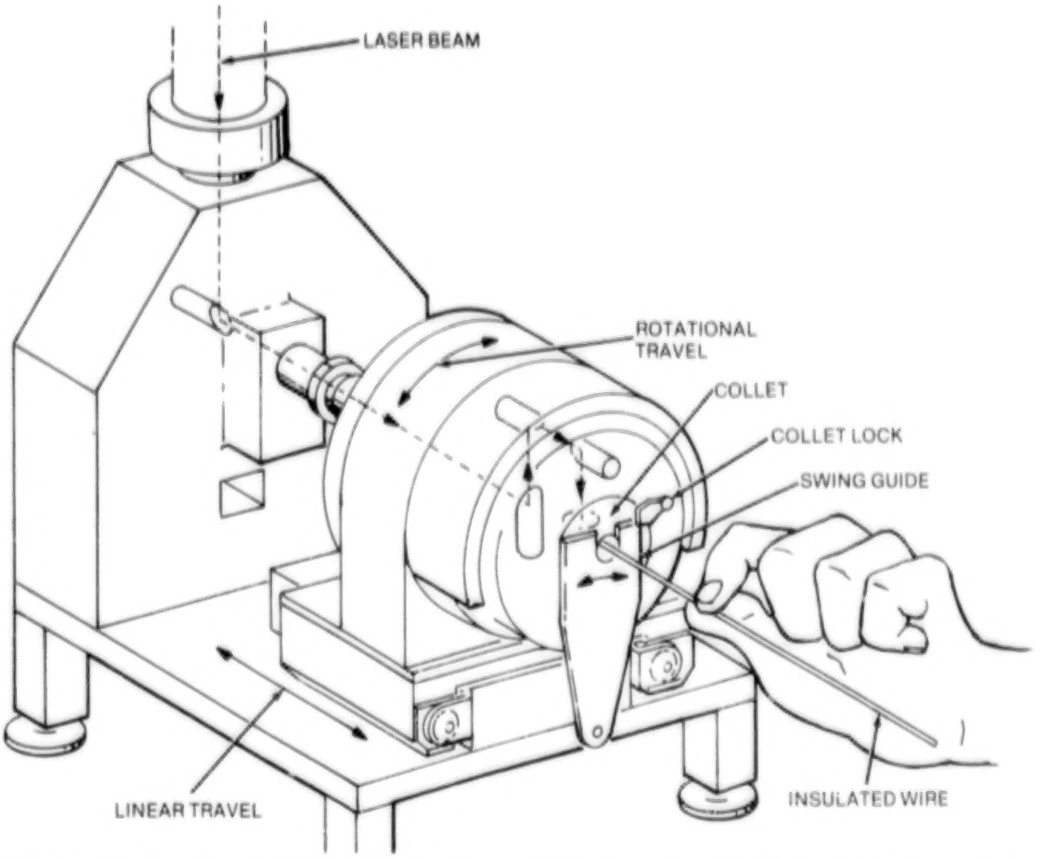


Figure 11. ***Rotating optical system,*** **consisting of three mirrors and a converging lens, rotates the focused laser beam about the fixed wire to produce a circumferential cut in the insulation. The optical assembly then moves axially to cut the insulation lengthwise. Both motions are controlled by dc motors with adjustable speeds.**

Rotating Optical System

The experiments described above used a wire holder that rotated the wire beneath the focused laser beam. To accommodate harness wires, a design concept was selected in which the focused laser beam is rotated around the fixed wire, as shown in Figure 11. The laser beam is initially reflected by a fixed mirror; then it is passed into the rotating joint and through the movable focusing optics. An assembly consisting of three mirrors and the output focusing lens revolves, rotating the laser beam and deflecting it onto the wire surface. Linear-axis travel of the optical assembly moves the beam along the wire.

Physical design requirements limit the mirror surfaces to a diameter of 0.2 in. To accommodate this dimension, the diameter of the laser beam is reduced by an aperature. The output focusing lens focuses the rotating beam to a spot size of 0.005 in., providing a power density of 10^5 W/in.^{2} for effective wire stripping.

Oxygen, introduced through the rotating joint, is discharged as a gas jet to assist the laser-beam stripping action.

Bench-Model CO_2 Laser Wire Stripper

A bench model of the laser wire stripper, using a modified laboratory 250-watt CO_2 laser and built for Space Shuttle production manufacturing, is shown in Figures 12 and 13. This model used the rotating optics described above.

The CO_2 laser generates coherent radiation at a wavelength in the far-infrared region (10.6 μm) that is invisible to the naked eye. The laser consists basically of a long glass tube, folded in the middle for ease of packaging, and contains six electrodes—two anodes and four

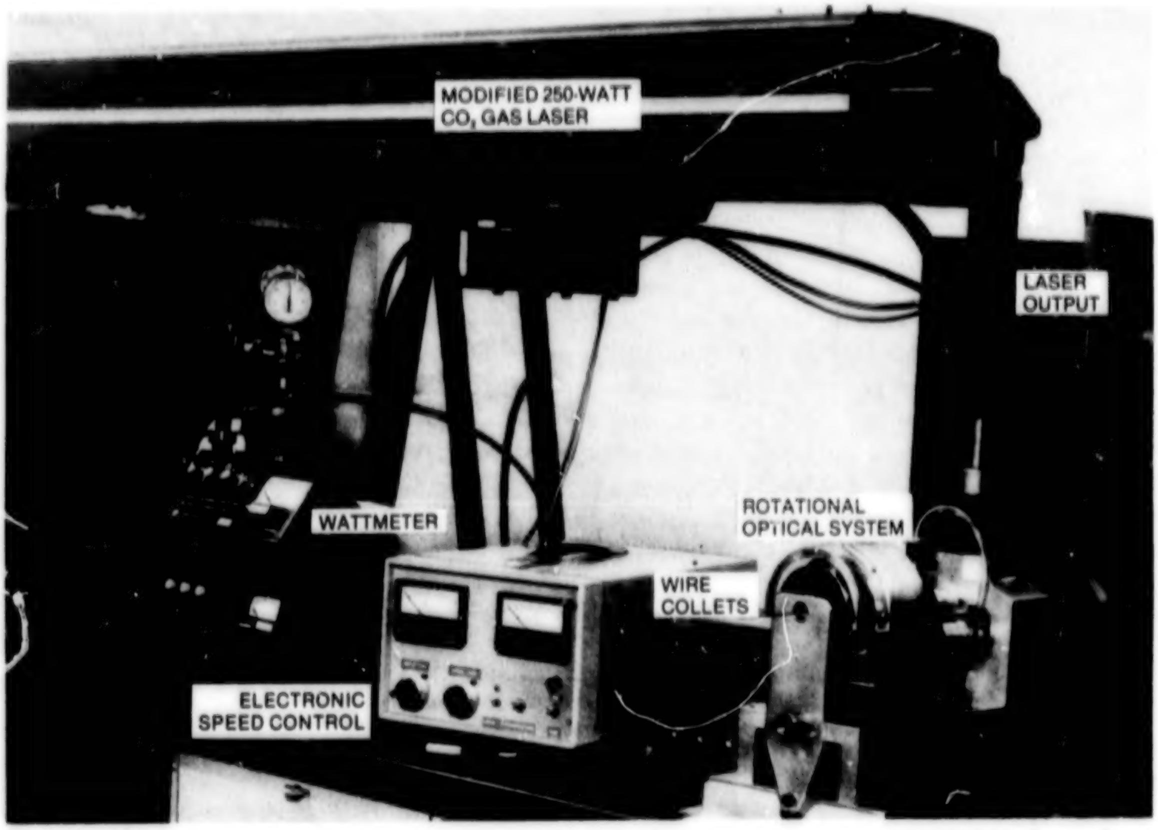


Figure 12. ***Bench-model CO_2 laser wire stripper,*** **used in production of wiring harnesses for NASA's Space Shuttle, has the rotating optical system and complete instrumentation.**

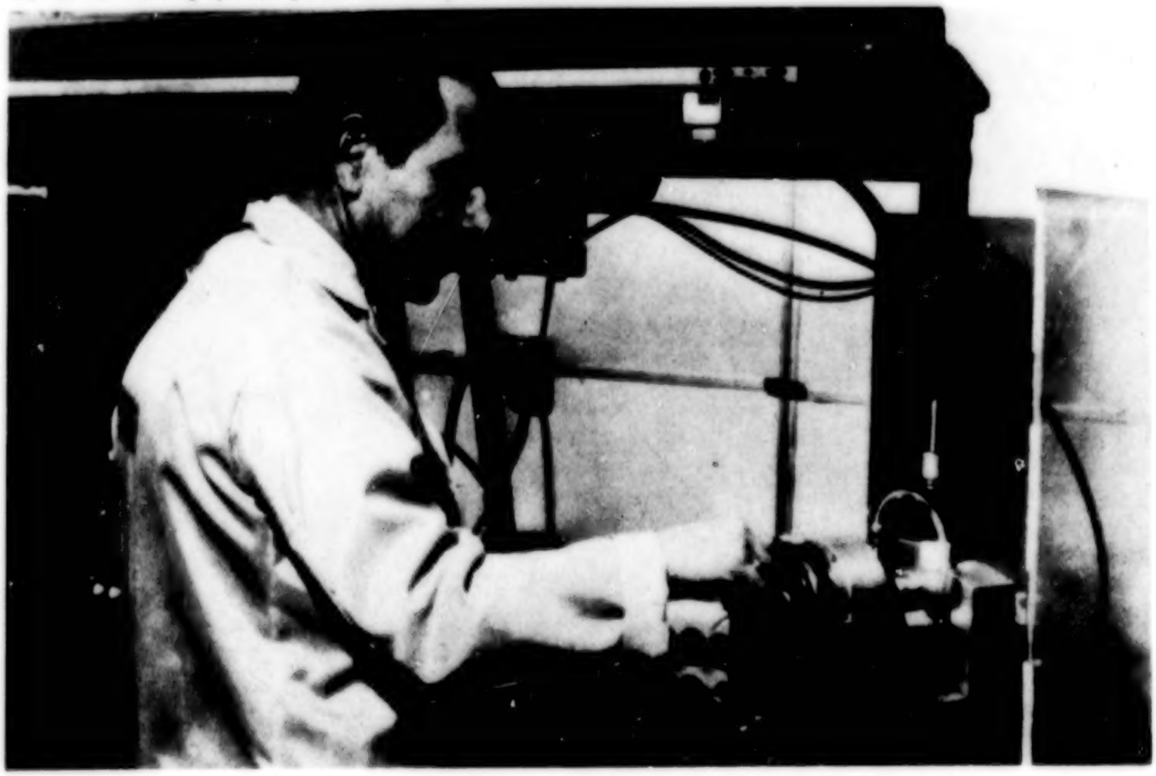


Figure 13. ***Application is demonstrated*** **in this photograph of the bench-model CO_2 laser wire stripper of Figure 12. Operators receive eight hours of training in use of this equipment.**

cathodes (see Figure 14). The tube has an inlet and an outlet; the gas supply is connected to the inlet and a vacuum pump to the outlet. This pump continuously draws on the tube. By use of a gas regulator, a flow pressure can be established and maintained in the low 10- to 20-torr range. The tube is cooled by water circulating through a glass jacket that completely encloses the tube. A large water cooler maintains the water temperature in the cooling system below 70° F (21° C).

The power supply produces 20-kV dc at 150 mA. To begin operation, the supply provides a higher voltage pulse to ionize the gas, after which the 20 kV is enough to sustain ionization. The mirror at the rear of the laser tube is 99-percent reflective at the 10.6-μm wavelength. At the front end of the laser, there is a mirror that reflects 95 percent of the light at 10.6 μm. When the radiation bouncing back and forth between these mirrors reaches the proper energy level, it produces a coherent beam about 3/8 in. in diameter with a power output of up to 15 watts through the front mirror. The power is monitored from the 1-percent transmission through the rear mirror.

The coherent beam is directed from a right-angle mirror into the rotating optics system toward the focusing lens. The focusing lens, made of germanium, is opaque to visible light, but it is 94-percent (or more) transparent at the 10.6-μm wavelength. Assisted by an oxygen jet, the beam strips the insulation from the wire.

An overall view of the stripping head and the collets for different wire size is shown in Figure 15. An exhaust system removes vapor and debris from the housing that surrounds the rotary unit.

The wire is inserted into the fixture through a swinging frame, which is moved to install the wire collet in the mechanism.

An operator strips a wire simply by inserting it into the collet and pressing a switch. The switch actuates the shutter, allowing the focused laser beam to impinge directly on the surface of the wire, and also controls the motors that rotate and translate the beam. Each dc motor has a feedback generator that is used in conjunction with a dc amplifier to control velocity. The speed-control equipment can be seen on the bench in Figures 12 and 16.

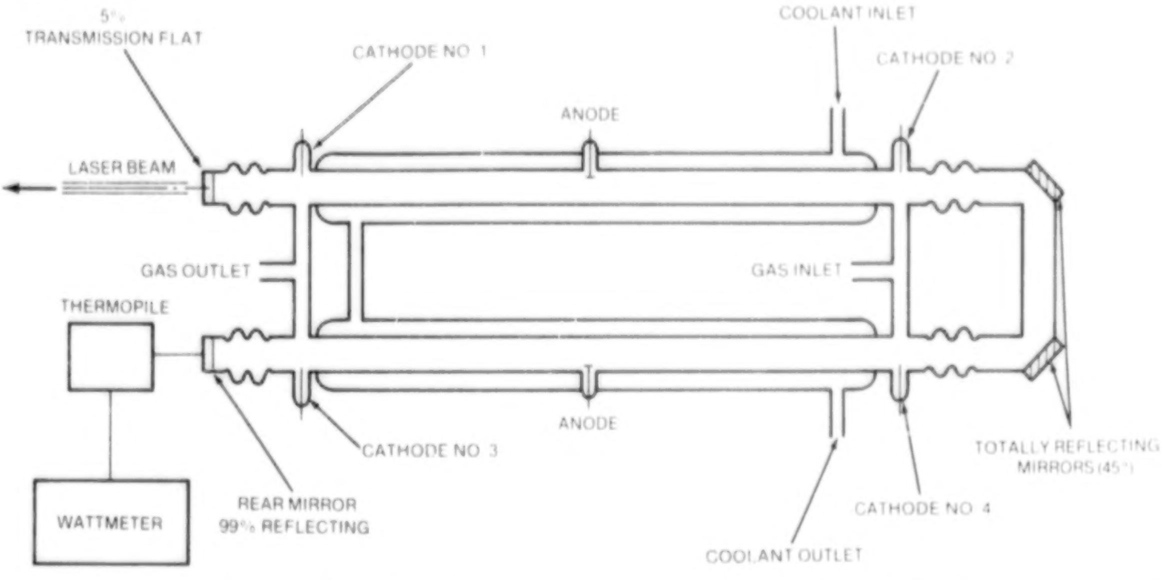


Figure 14. ***Inside the laser*** **is a water-cooled glass tube containing a mixture of gases at low pressure. Electrical discharge excites the gas molecules to produce coherent radiation in the cavity formed by the end mirrors.**

Although Figure 12 shows only one stripping station being driven by the laser, several stations could be driven by a single laser. The multiple-station concept is described in Chapter 4.

Hand-Held CO_2 Laser Wire Stripper

A hand-held wire stripper that contains a compact 2.5-watt CO_2 laser is shown in Figure 17. This unit is connected to a control cabinet by a counterbalanced arm carrying cables and hoses for high-voltage power, the CO_2 gas mixture, and cooling water to the laser, as well as power, oxygen, and exhaust for the rotating optical assembly. The control cabinet itself, shown in Figure 18, houses the power supplies, servocontrols, and water and vacuum pumps.

The compact CO_2 laser that is the heart of this stripper was developed for use in communication satellites and initially achieved a 1.3-watt beam power rating. It is shown in the photograph in Figure 19 and in the schematic diagram in Figure 20. It is called a waveguide laser because the electrical discharge and radiation cavity are contained within the narrow inner diameter of a beryllium oxide tube. The BeO tube is inside a larger diameter cylinder that holds the CO_2 gas mixture at a pressure somewhat below atmospheric (approximately 110 torr). This laser does not require a continuous

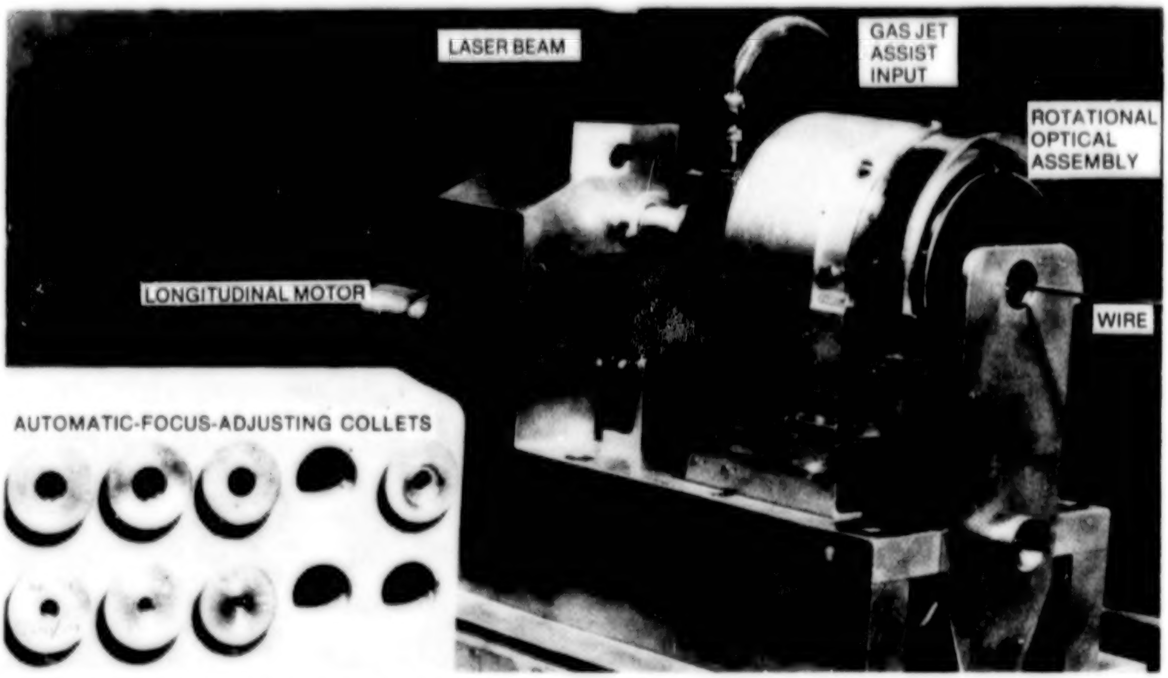


Figure 15. ***A collet for each wire size*** **from AWG 26 to AWG 1/0 is part of the equipment for the laser wire stripper. The collet holds the wire and automatically positions the focusing lens.**

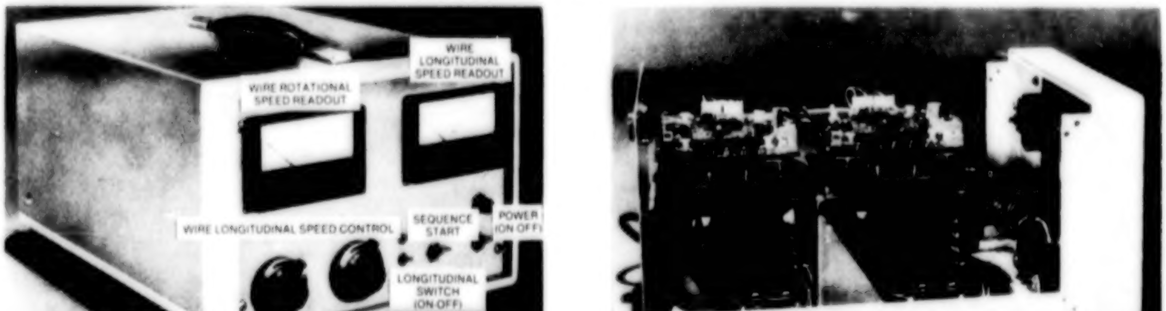


Figure 16. Speed Control for adjustment of the rotational and longitudinal cutting rates in the laser wire stripper. Each dc motor is controlled by a servoamplifier. Figure 16[b] shows the cover removed.

flow of gas. It is rated for 80 hours of continuous operation, after which it can be pumped out and refilled when the output power drops below the rated power. Recent refinement of this small laser has increased its rating to 2.5 watts.

The output beam from this laser is 1 mm in diameter, so it must be expanded (by divergence and recollimation) before entry into the rotating optical system, as shown in Figure 21. The 2.5-watt power level is adequate to maintain the same stripping speeds as the bench-model unit for wire 12 gage or smaller.

Hand-Held Nd:YAG Laser Wire Stripper

Instead of running cables and tubes to the laser in a hand-held wire stripper, it may be more convenient to place the laser in the control cabinet and transmit its output light beam to the rotating optical assembly in the hand unit through flexible optics. This technique is used in the wire stripper shown in Figure 22 and 23; the light beam is carried to the stripper head by a special fiber-optic cable. The laser used in this system cannot be a CO_2 type, because presently available fiber optics cannot transmit the 10.6-μm infrared radiation from such lasers. Instead, a commercially available larger 10-watt

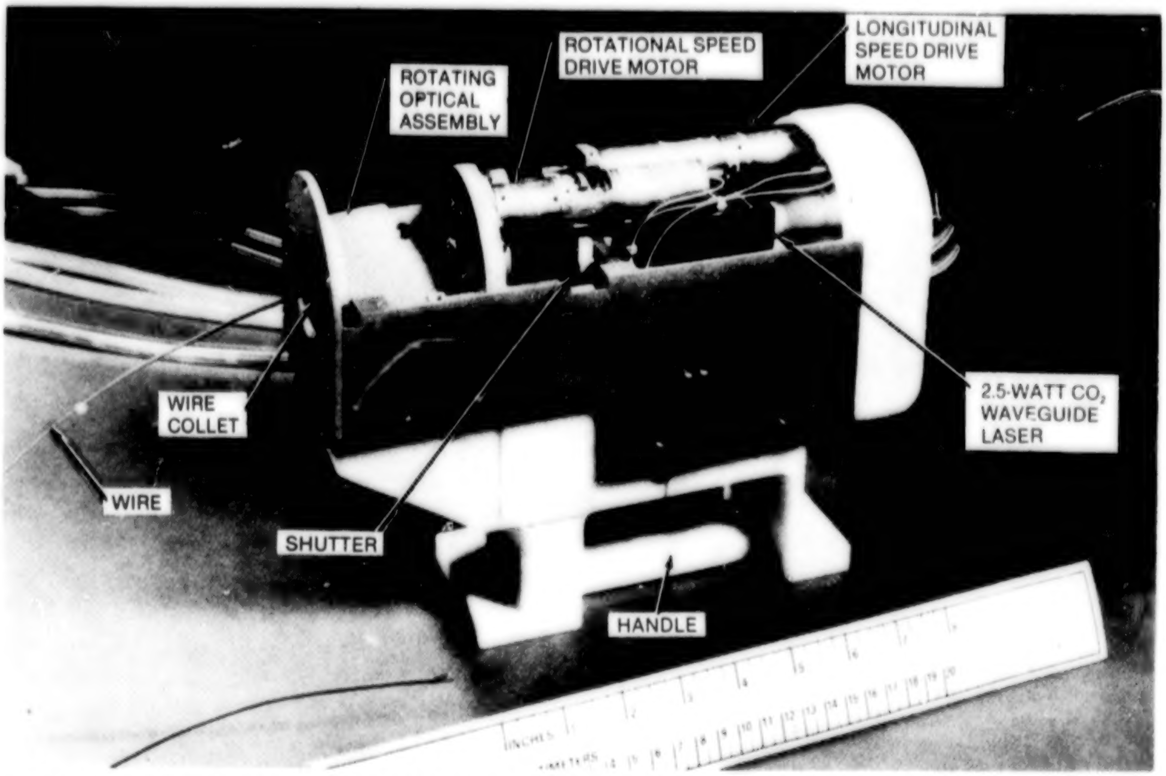


Figure 17. A *miniature 2.5-watt CO_2 laser unit* is integral with this hand-held portable wire stripper for wire sizes 26 through 1/0 gage. An umbilical cord containing electrical, gas, and water lines connects the stripper to the control cabinet.

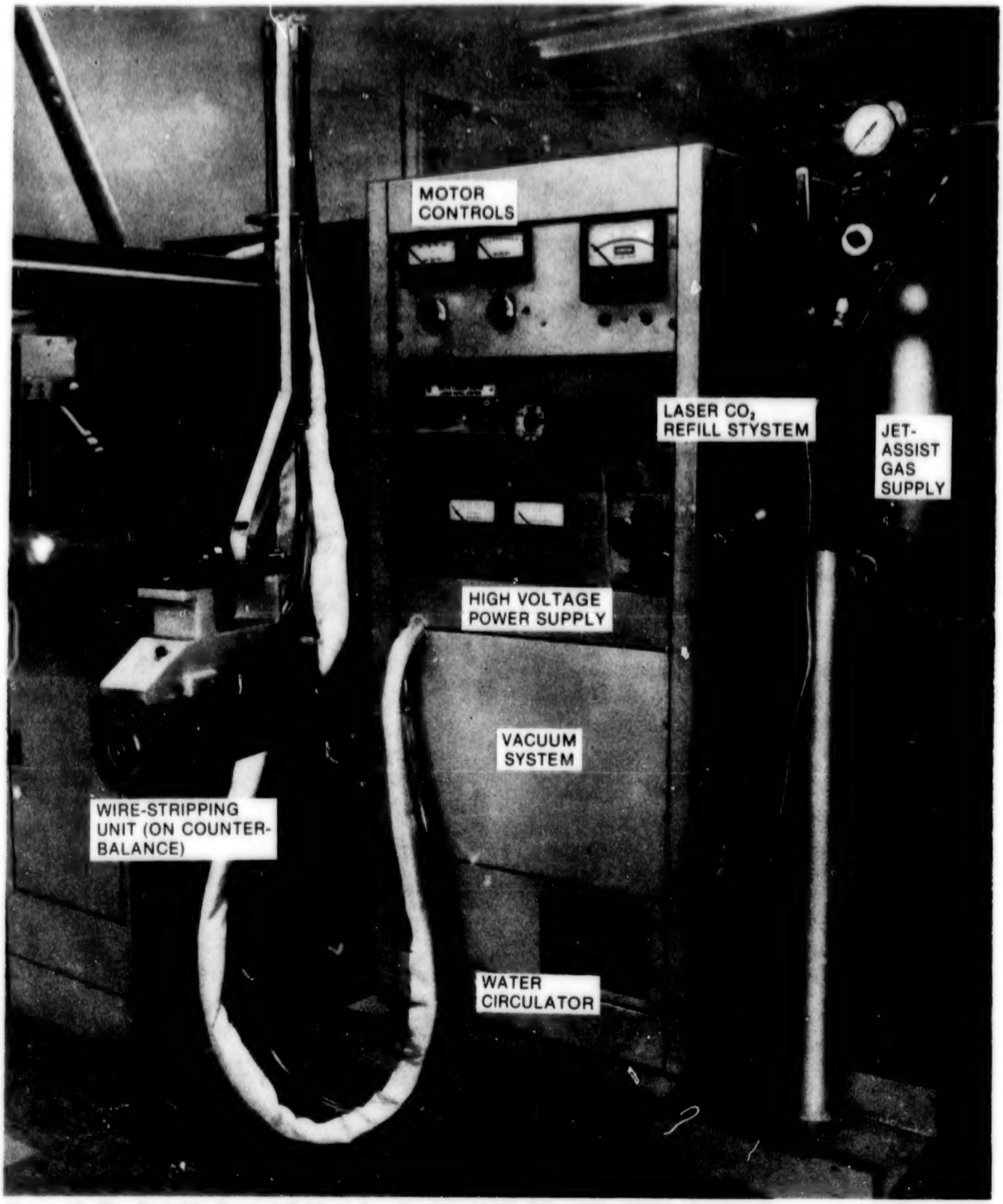


Figure 18. The Portable Control Cabinet for the hand-held CO_2 wire stripper houses the power supplies, servo-controls, and water and vacuum pumps.

solid-state laser (see Figure 26[b]) that emits coherent radiation at 1.06 μm is used. Greater input power is required because the shorter wavelength laser does not operate as efficiently. It is not effective on Teflon insulation.

The laser is a rod of yttrium-aluminum-garnet (YAG) crystal, doped with neodynium (Nd). When the Nd atoms in the Nd:YAG lattice are excited by light shone on the rod, they emit the 1.06-μm radiation. The beam reflects back and forth between mirrors on the polished ends of the rod, achieving coherence. Beam power of approximately 7 to 10 watts passes through the 95-percent-reflecting output mirror into the bundle of silica fibers.

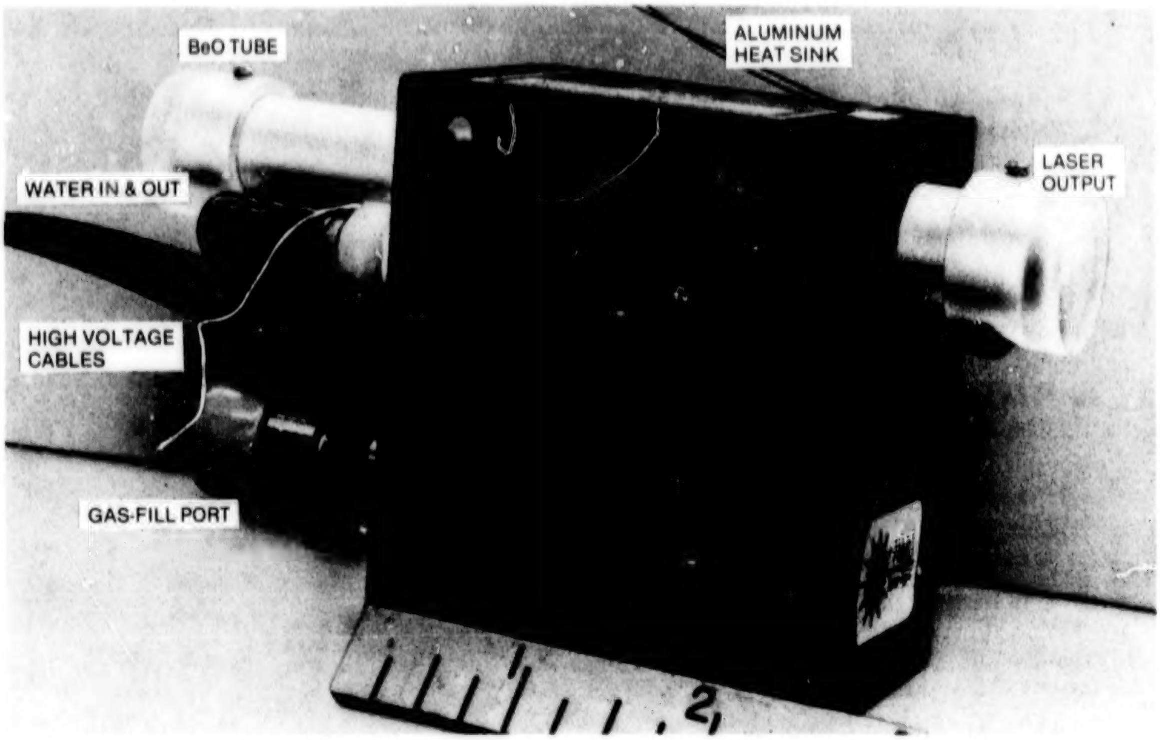


Figure 19. ***Miniature CO_2 laser*** **that powers hand-held wire stripper has a rated output of 2.5 watts at 10.6 μm. It contains a fixed charge of gas mixture, which can be changed if necessary. The laser was originally rated at 1.3 watts.**

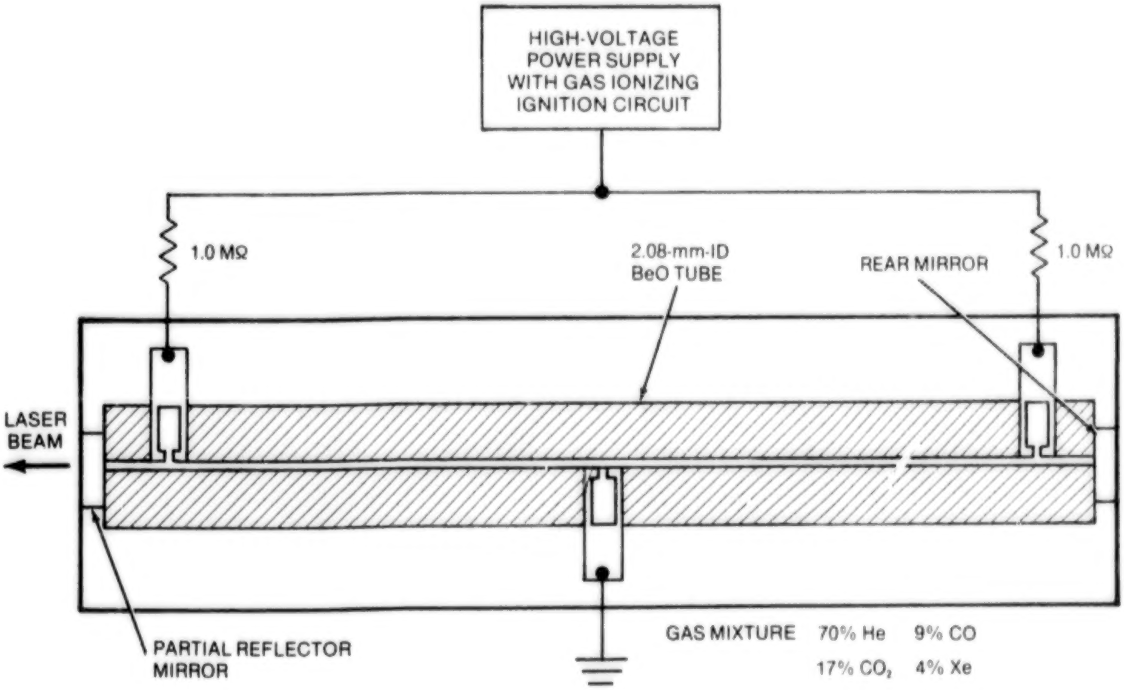


Figure 20. Diagram of the miniature CO_2 laser shows a beryllium oxide tube with a narrow inside diameter that contains the plasma gas. End mirrors create the optical cavity in which coherent radiation builds up. Heat sinking and water cooling are not shown.

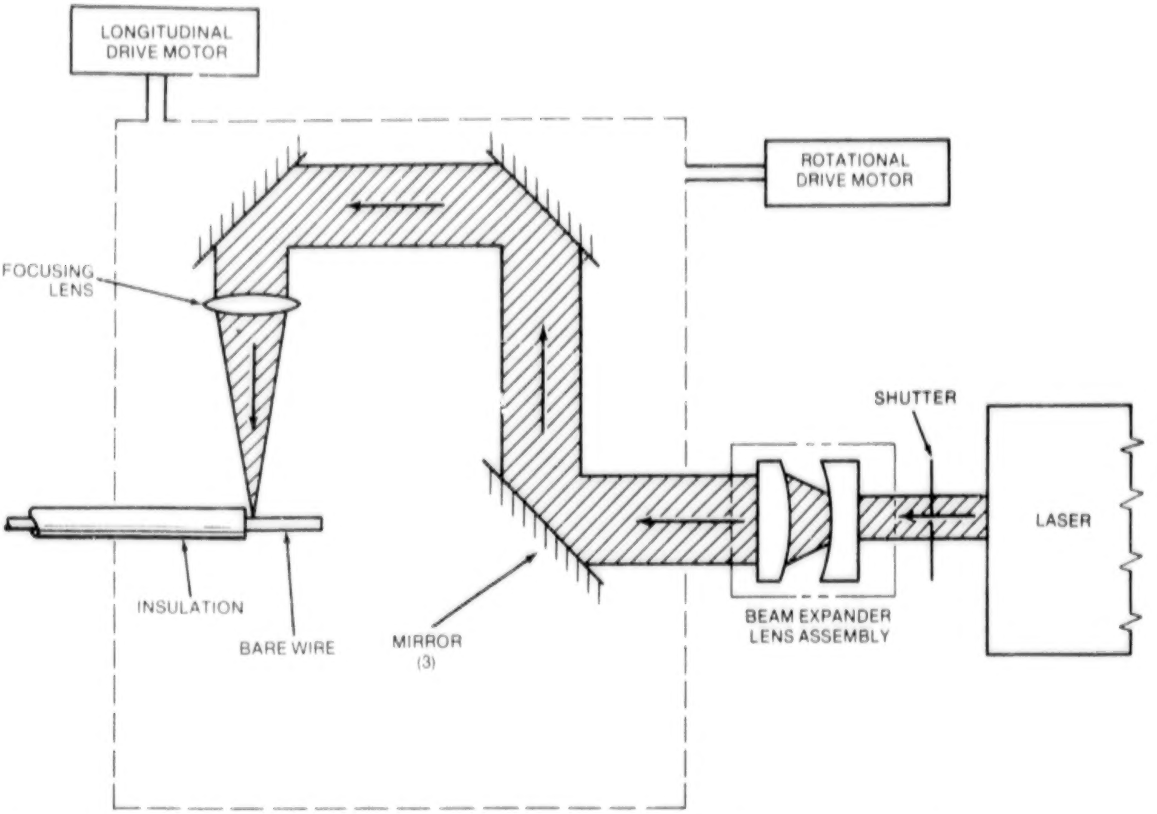


Figure 21. Schematic of CO_2 *hand-held laser wire stripper* shows path of 1-mm-diameter output beam from laser through a beam-expander lens assembly before entering rotating optical system.

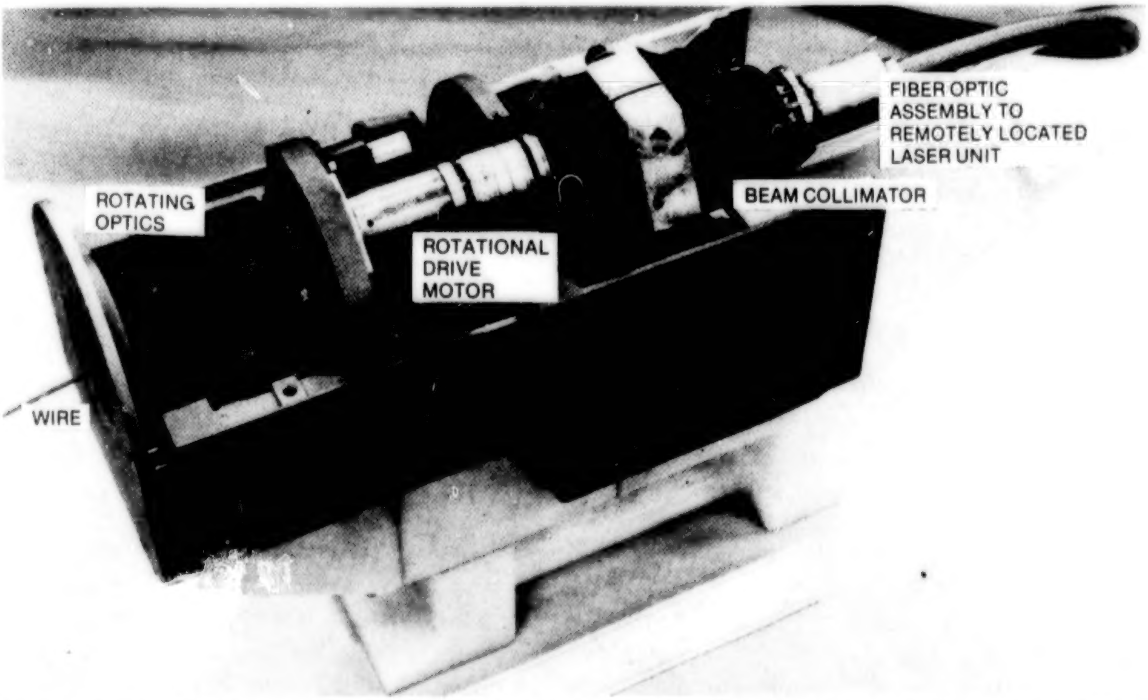


Figure 22. *Hand-held laser wire stripper* modified for use with a flexible fiber-optic cable that brings in 1.06-μm radiation from a remote Nd:YAG laser.

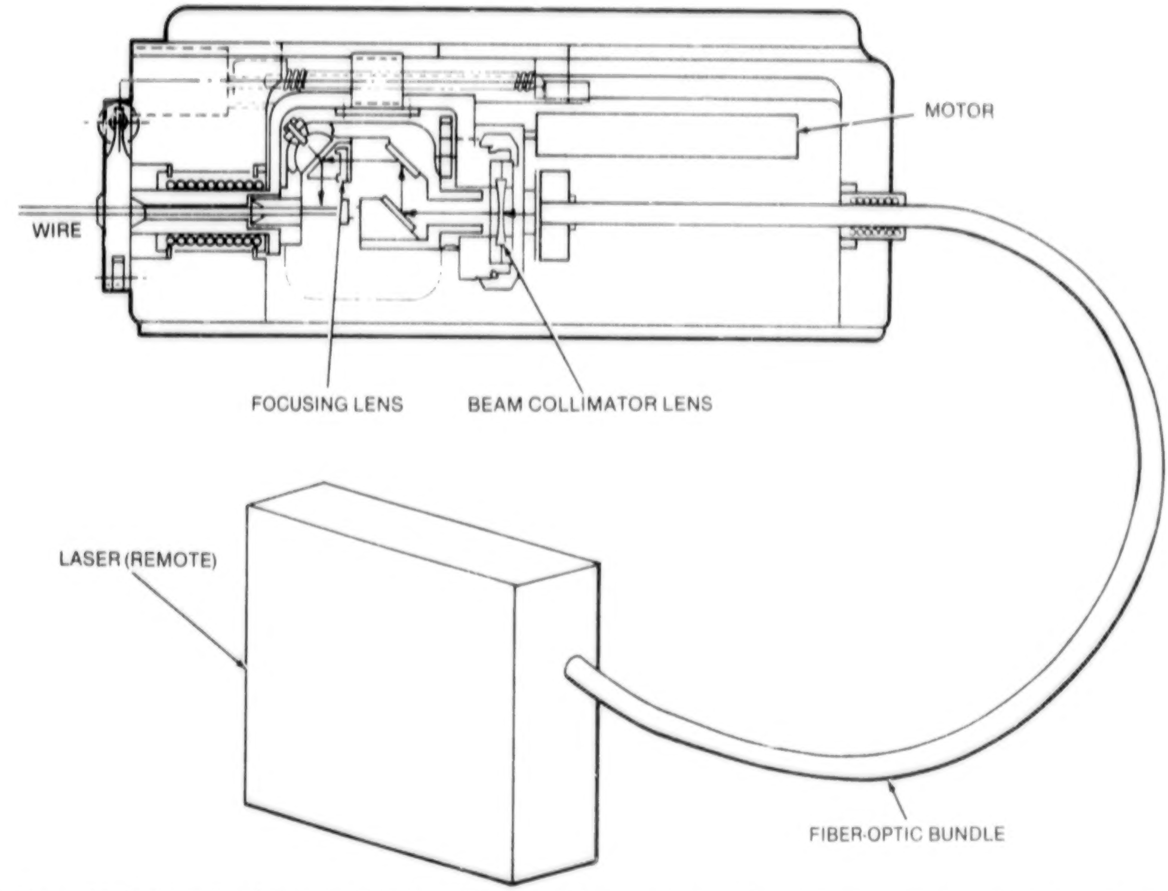


Figure 23. Schematic of *remote-laser hand-held wire stripper* system. Coherent radiation is emitted at 1.06 μm from Nd:YAG laser, passes through fiber-optic cable and collimator lens before entering rotating optical system.

The optical transmission properties of the silica fiber are shown in Figure 24. The power loss at 1.06 μm is less than 20 dB/km. The 12-ft-long bundle used for the wire stripper has an overall transmission efficiency of 85 percent. The light emerges with a divergence of 16° and is collimated by a converging lens before entering the rotational optics, as seen in Figure 25.

After the beam has been reflected by the three 0.2-in.-diameter rotating mirrors, a short-focal-length lens focuses it at the wire surface with a spot diameter of approximately 0.003 in. With this spot size, power density greater than 10^5W/in.^{2} becomes available and compensates in part for the lower heating efficiency of the short wavelength. A 7-watt beam achieves rapid stripping on polyimide (Kapton)-insulated wire sizes No. 26 through 1/0. Oxygen is used for the gas-jet assist, and a vacuum exhaust filter system removes debris and vapors.

The production model of the hand-held Nd:YAG laser wire stripper with fiber-optic assembly is shown in Figure 26. The entire assembly is mounted on a portable cart that carries the cooling unit, laser power control, laser, electronic speed control, and counterbalance. With the counterbalance (see Figure 26[b]) very little operator effort is required to position the 8-lb stripper. Further details of the control elements mounted on the cart are shown in Figures 27 through 30.

The beam from the Nd:YAG laser can be fed into the previously described (Figure 12) bench-type laser stripper in place of the beam from the CO_2 laser. Figure 31 illustrates such operation. In this figure, the output from the fiber-optic bundle has replaced the CO_2 laser output.

A single laser can be used to drive several hand-held and/or bench-type wire strippers. Techniques for such operation are described in Chapter 4.

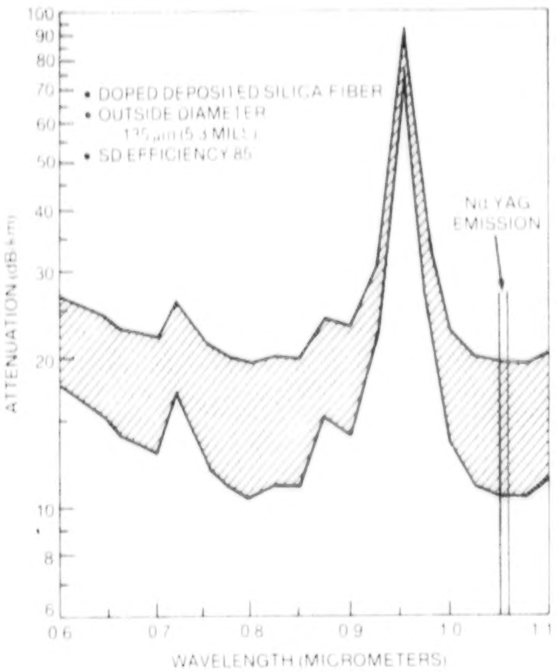


Figure 24. ***Optical transmission properties*** **of silica fiber. Power loss at 1.06 μm is less than 20 dB/km, and the transmission efficiency of a 12-ft bundle is 85 percent.**

Operating the Wire Strippers

Eight hours of instruction have been found adequate to teach an operator to use the laser wire stripper. The training includes operating procedures, equipment maintenance, and strong emphasis on safety practices and precautions.

The operating procedures for the bench-mounted CO_2 laser wire stripper and for the cart-mounted hand-held Nd:YAG laser wire stripper are presented on pages 21 and 22, respectively.

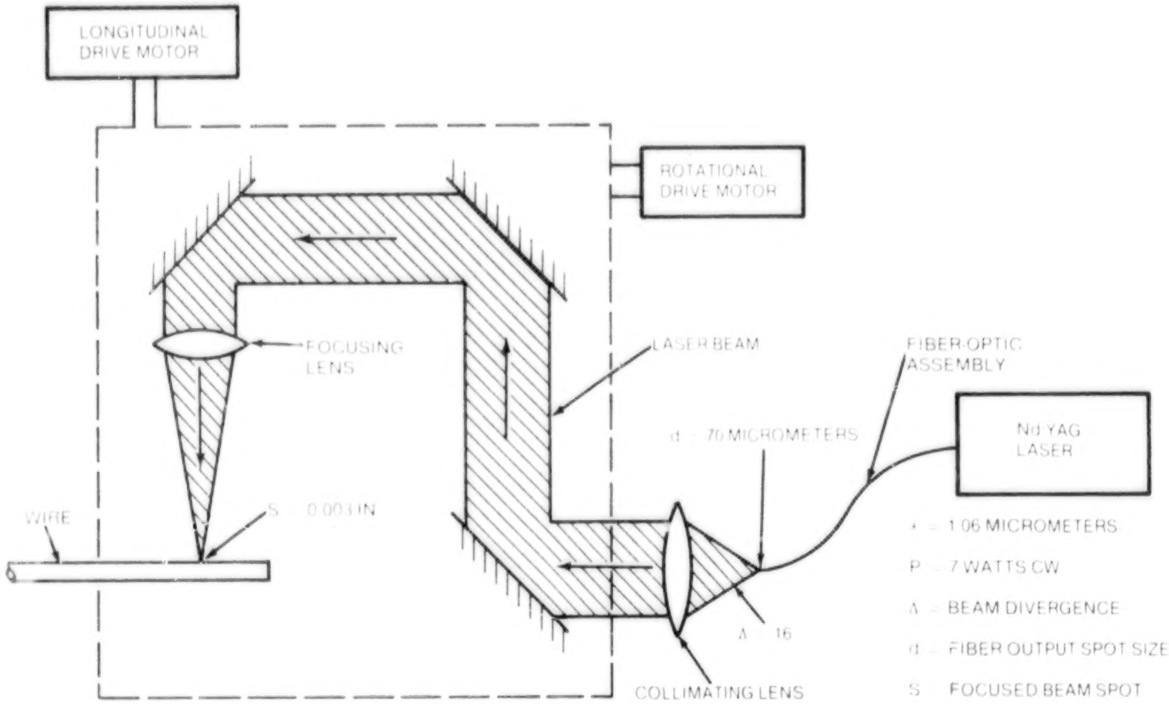


Figure 25. Optics of ***Nd:YAG hand-held laser wire stripper*** **system. Beam exits from fiber optics with 16° divergence and passes through collimator lens into rotating optical system.**

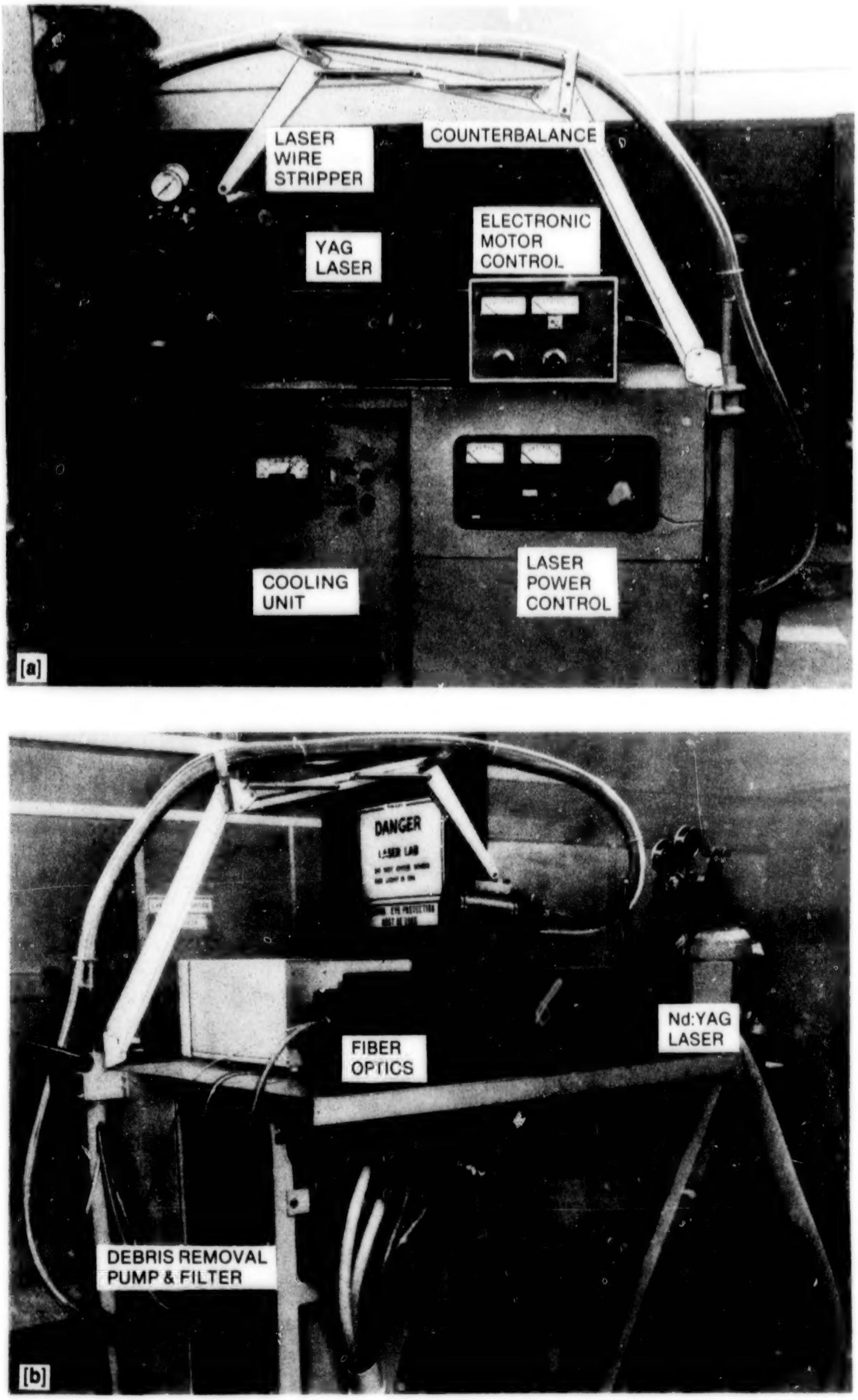


Figure 26. ***Cart-mounted Nd:YAG laser wire stripping system,*** **consisting of a portable counterbalance-suspended hand-held stripping unit connected by a 12-ft cable to laser, utilities, and controls on a cart that can be rolled to various production areas. The Nd:YAG laser is partly visible on the top of the cart in (a). The hand-held stripper unit with its rotating optics stripping head receives its laser beam through a fiber-optic input. In (b) the rear view of the cart-mounted unit shows additional details of the accessory equipment. In particular, the laser and its fiber-optic output cable are clearly visible on the top of the cart.**

Operating instructions for the bench-mounted wire-rotating CO_2 laser wire stripper (Refer to Figures 8 and 9)

To turn on and use the stripper, proceed as follows:

1. Turn on cooling unit, water pump, and condenser unit.
2. Turn on oxygen, set regulator to 30 psi.
3. Turn on laser gas cylinder.
4. Turn on vacuum pickup system.
5. Turn on power-control unit, set beam-select switch to ON, adjust pressure to 10 torr.
6. Turn on optical power meter, verify that range-select switch is on 100, readjust to zero after warmup.
7. Turn on shutter-control unit, verify that shutter-select switch is in the OFF position.
8. Turn on electronic speed control, observe warmup period.
9. Depress rotation switch on electronic speed control and adjust gas-jet assist to 20 CFH.
10. With rotation switch depressed, set rotation speed for size of wire to be stripped.
11. Set longitudinal speed as required, verify longitudinal switch is in ON position, depress rotation switch momentarily. (Note: longitudinal meter reads after rotation switch is released.)
12. Insert collet into wire tool fixture. (Collet screws into a threaded spring-loaded collet holder, adjust until spring cannot be seen.)
13. Depress collar on collet holder and insert wire.
14. Set vertical adjustment.
15. To center laser beam relative to the wire, depress momentary switch on shutter-control panel. Observe wire and make adjustments as necessary.
16. Insert wire into collet and momentarily depress the wire-rotation switch. Remove wire from the fixture. Inspect and reset the longitudinal and rotational stripping speeds if required.
17. If only rotational strip is required, set longitudinal/rotational switch to ROTATION.

To shut down the unit after use, proceed as follows:

1. Turn off electronic speed control.
2. Turn off power-control unit.
3. Turn off optical power meter.
4. Turn off shutter-control panel.
5. Turn off laser gas cylinder.
6. Turn off gas-jet assist.
7. Turn off vacuum exhaust system.
8. Turn off cooling system.

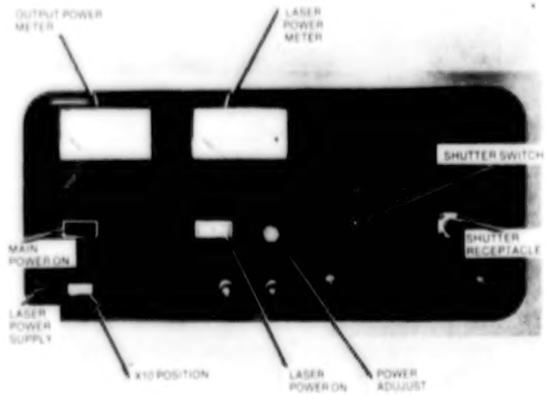


Figure 27. ***Power control*** **for the Nd:YAG laser.**

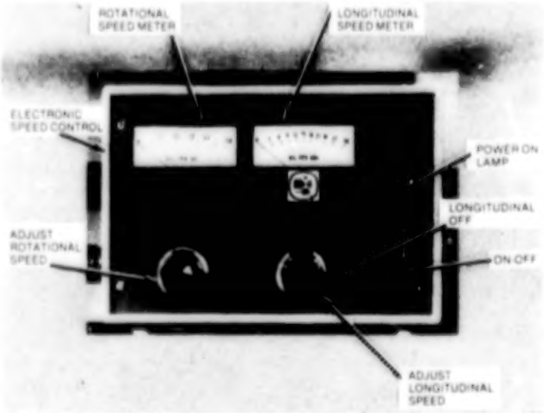


Figure 28. ***Electronic speed control*** **for the motors in the rotating optical system of the Nd:YAG laser wire stripper.**

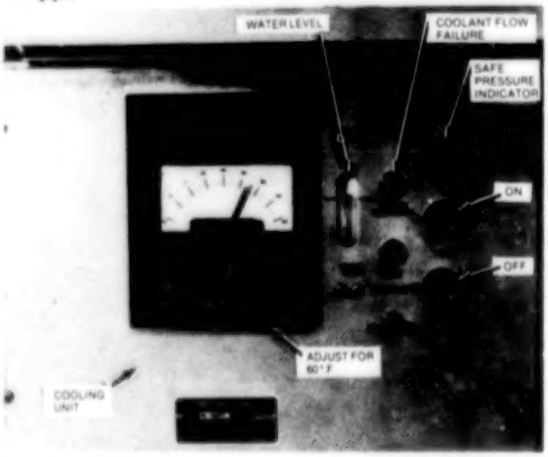


Figure 29. ***Cooling-unit controls*** **for the Nd:YAG laser.**

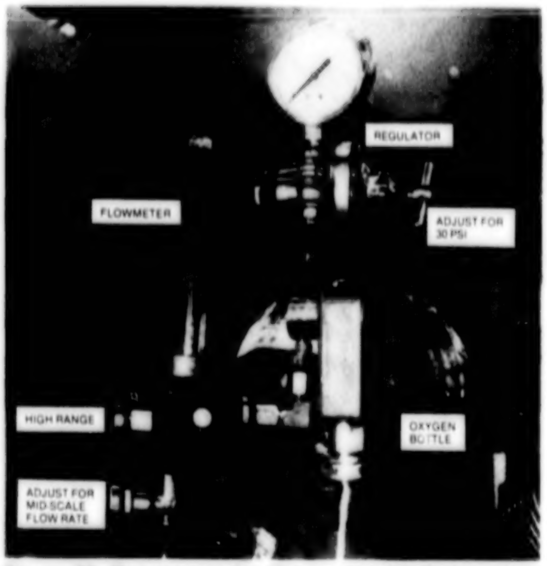


Figure 30. ***Gas source*** **for the oxygen jet that assists wire stripping and protects the lens in the Nd:YAG wire-stripping unit.**

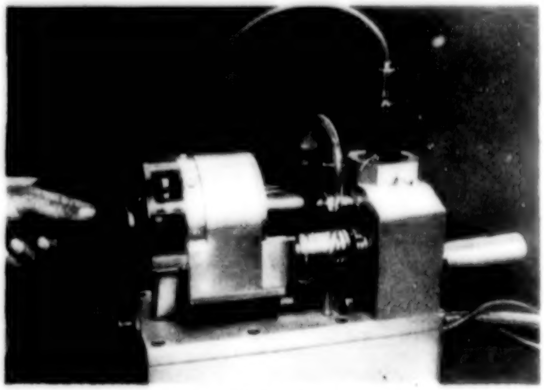


Figure 31. ***Fiber-optic feed adaptor*** **for bench-type laser wire stripper. The CO_2 laser input for this bench stripper is shown in Figure 12.**

Operating instructions for rotating optics Nd:YAG laser wire stripper [Refer to Figure 26]

To turn on and use the stripper, proceed as follows:

1. Turn main power switch on.
2. Press start button on cooling unit to turn on water pump and condenser.
3. Adjust water temperature for 60° to 70° F. Verify that coolant-flow failure lamp is off and safe-pressure lamp is on.
4. Turn main power switch of laser power control to ON. Verify that shutter switch is off, and that range switch for output power meter is set to 10X position.
5. Turn laser power switch to ON. Wait 30 seconds for reading on laser power meter to stabilize, then adjust reading to 3 kW using power-adjust control. Check for output on output power meter by momentarily turning shutter switch to ON and then OFF.
6. Turn power switch of electronic speed control to ON.
7. Open main valve of oxygen bottle and check pressure.
8. Adjust regulator for output pressure reading of 30 psig.
9. Check flowmeter range control for high range position.
10. Push in and hold laser ON button (located on stripper unit) and adjust oxygen flow rate for a midscale reading on flowmeter.
11. Verify that shutter switch is off.
12. Check applicable documents for required wire size and strip length.
13. Select correct collet, strip-length stop for collet, and rotational and longitudinal stripping settings. Then set controls on electronic speed control accordingly.
14. Install wire stop in collet and install completed collet into stripping unit.
15. For combined rotational and longitudinal stripping, set longitudinal switch to ON. For rotational stripping only, turn this switch to OFF.
16. Insert dressed end of wire into stripper until the end reaches the wire stop.
17. Press laser push button and observe movement of collet.
18. Withdraw wire from stripper after complete rotational/longitudinal movement of collet.
19. Move the slug slightly to verify complete detachment. Do not remove slug until wire is ready to be terminated.

To deactivate the system, proceed as follows:

1. Turn off electronic speed control.
2. Turn off both laser power and main power switches of laser power control.
3. Close main valve on oxygen gas bottle.
4. Turn off cooling system.
5. Turn off main power switch on console.

CHAPTER 4
ADDITIONAL TECHNIQUES AND MODIFICATIONS

During and since the development of the prototype laser wire strippers described in Chapter 3, several modifications or improvements have been made in four basic areas:

- the laser
- the optics
- the control system, and
- cutting techniques.

Some of these developments are designed to make the laser wire stripper more suitable for particular applications, while others are useful under most or all circumstances.

As presented below, each of these innovations is accompanied by a NASA control number. The individuals responsible for the particular innovation are listed in the appendix. An asterisk by the NASA control number indicates the availability of additional documentation, such as tool drawings or schematics. Refer to the appendix for information on how to obtain such material.

Laser Considerations and Characteristics

Concept for Portable CO_2 Laser With Rotating Optics (MSC-19369)

The initial concept for a portable hand-held laser wire stripper, using a miniaturized CO_2 waveguide laser, is shown in Figure 32. The features proposed included the basic hand unit with rotating optics and the accompanying portable power and control unit as later developed (pages 13 and 14, Figures 17 and 18). The original miniaturized CO_2 laser that was the basis for the design concept was rated at 1.3 watts; the rating was upgraded to 2.5 watts by subsequent refinements, including the improved temperature control described in New Technology Report MSC-19558 (see page 25).

Concept for Portable Nd:YAG Laser with Fiber-Optic Connector (MSC-19418)

Experiments demonstrated that optical fibers could transmit the 1.06-μm laser beam from a laboratory Nd:YAG laser to the cutting head to strip polyimide-insulated wire. The fiber-optic laser-beam transmission thus could avoid the use of the high-voltage coaxial cable required to connect the cart-mounted power supply to the hand-held CO_2 laser. Disadvantages were that the lower wavelength beam from the YAG laser required greater power to heat insulation and was not effective on Teflon insulation. The unit offered possible safety features for use with polyimide (Kapton) insulated wiring. While oxygen gas assist was not required for cutting with the YAG laser beam, some gas flow was still needed to prevent contamination of the lens surfaces. Less-expensive optical glass lenses could be used.

For final development of this breadboard effort, see the description starting on page 14.

Nd:YAG Fiber-Optic Hand-Held Laser Wire Stripper (MSC-19770*)

A hand-held laser wire stripper prototype, based on the fiber-optic concepts discussed in the preceding paragraphs, was built for Shuttle production use. A portable cart requiring a 2,000-watt power connection supplies the hand unit through an umbilical cable carrying the fiber optics together with exhaust, cooling, and gas supply lines. Fiber-optic extensions can be made so the 8-lb stripper head can be detached from the arm and hand-carried into large structural assemblies. This cable could be up to 100 ft in length, or longer if required.

This Shuttle unit is described on page 18 and shown in Figure 26.

Rotating Optical System

The optical system in the laser wire stripper focuses the laser beam to the smallest possible spot size on the insulation to be cut. To make a circumferential cut around the wire without turning it, the laser beam has to be rotated; and to slit the insulation along the wire, the laser beam has to be moved longitudinally. The arrangement of three mirrors and a converging lens that permits the rotary and longitudinal motions (described on page 10) was incorporated as illustrated in Figure 32 (b). Further refinements are described in the following reports.

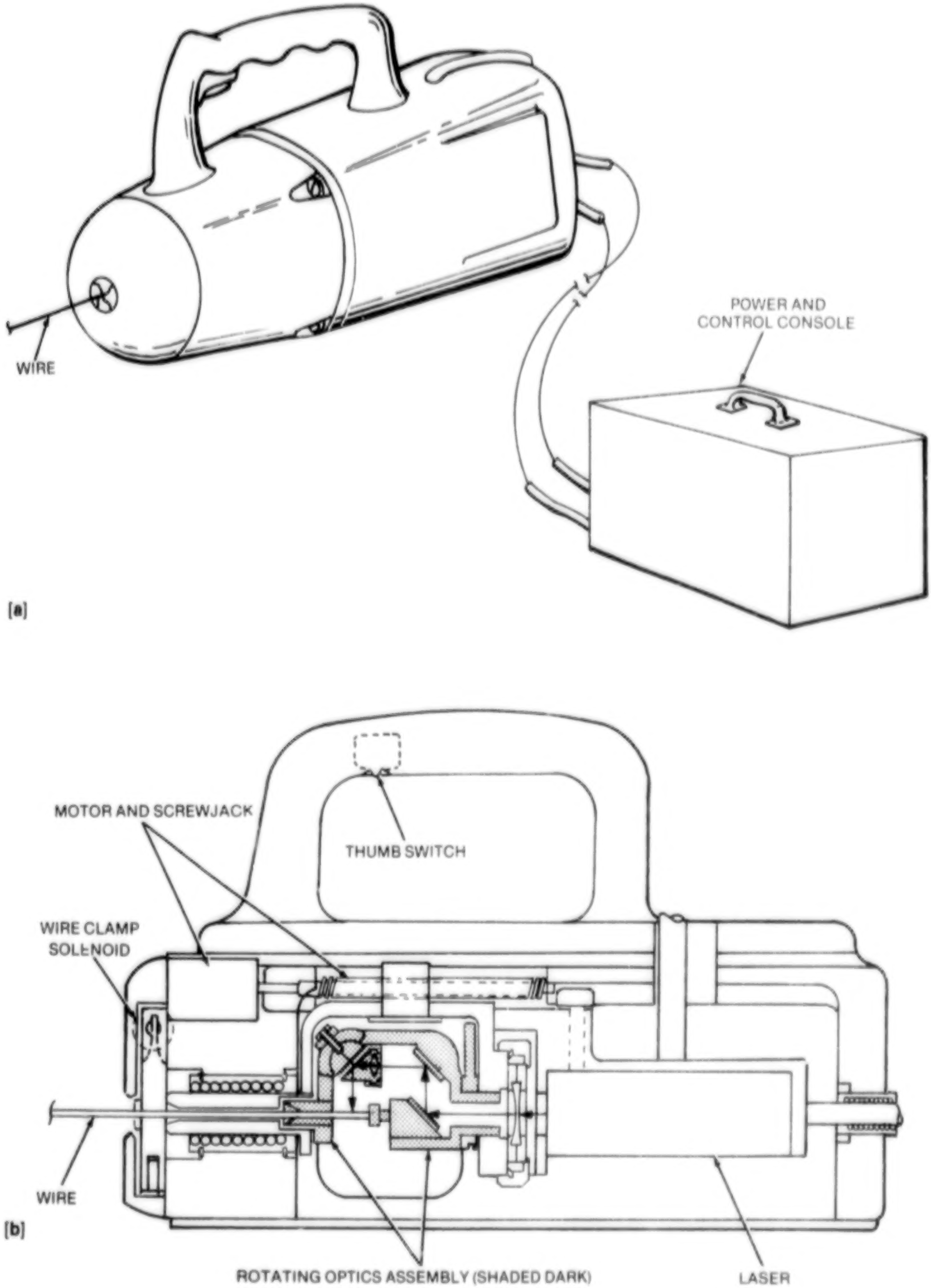


Figure 32. *Hand-held CO_2 laser wire stripper.* Original design concept sketch (a) shows a hand-held unit connected by flexible cable to its power-control support unit. The stripper head (b) contains the laser and the dynamic optical system for making circumferential and longitudinal cuts in the insulation. (MSC-19369)

Automatic Focusing of Rotating Optics (MSC-19496)

A novel wire-guide bushing for the rotating optics in laser wire strippers incorporates an appropriately tapered nose cam on each of the interchangeable bushings for different-sized wires. This feature is incorporated in all present Shuttle production laser wire strippers. The cam automatically slides the spring-loaded lens barrel to the position for exact focusing on the conductor. This procedure eliminates manual focusing, which is less accurate and more time-consuming. It is particularly important for hand-held strippers in order to ensure fast and foolproof control of the beam focus, and is very useful with bench units that must be changed frequently to different wire sizes.

Figure 33 shows that as the tapered nose (T) is pushed through the lens barrel opening, its larger diameter positions the lens exactly for the particular wire size. For wire sizes from AWG 26 to 1/0, an adjustment of approximately 0.250 in. is needed.

Interchangeable Optics for Different Lasers (MSC-19571*)

Interchangeable lenses and windows permit use of the rotating stripper with either YAG or CO_2 lasers. Each laser type may have advantages for particular insulations or operations; the interchangeable optics thus offer greater adaptability of the unit.

Figure 31 shows the bench-type laser wire stripper with a fiber-optic input from the YAG laser. Its 1.06-μm beam is transmitted through glass with little attenuation. Figure 12 shows the same unit with input from a CO_2 laser; germanium lenses are required to transmit its 1.06-μm beam.

Manual Laser Wire Stripper for Large Cable (MSC-19541)

A proposed manually-rotated bench attachment, for use with the fiber-optic laser unit of the hand-held wire stripper, strips insulation from large electrical cables. The fiber-optic bundle twists one turn around the end of the cable, which eliminates the need for the rotating lens system. This accessory could extend the use of the stripper to cables larger than 1/0 gauge. No prototype has been built.

A small hollow bearing, as shown in Figure 34, would be attached to the "handle" that houses the fiber-optics transmitting the laser beam. The bearing would clamp to a workbench, and the cable inserted and locked in place with a cable-adjust screw. The bearing would allow a circumferential cut to be made by manually rotating the handle and the power-cable/coolant-hose bundle. Rotating mirror optics are not required.

Figure 35 shows a large cable end that has been manually laser stripped to simulate the proposed device. A girdle-and-slot cut can be made to permit retention of the protective end slug until ready for connection.

Control System Elements

Multiple Stripping Stations From One Laser (MSC-19747)

Several laser wire-stripping units can operate either simultaneously or on a time-sharing basis from a single laser beam by using beam splitters to distribute the beam to each stripper. This concept permits wider use of laser wire strippers on production lines.

A 250-watt (or larger) CO_2 laser unit can continuously supply ten or more fixed bench-mounted wire strippers, as shown in Figure 36. A 10-watt Nd:YAG laser can supply several fiber-optic-connected hand-held portable laser wire strippers, but a time-sharing system is needed to operate one stripper at a time. Figure 37 shows such an arrangement.

Technical analysis indicates that an appreciable reduction in the cost of laser wire strippers for production wiring operations can be made by this concept. The design uses commercially-available beam splitters, fiber optics, and accessories, so no basic development is required.

Improved Temperature Control (MSC-19558*)

Laser wire-stripper performance is improved by a small temperature sensor attached directly to the laser body. This sensor replaces the fluid-flow temperature sensor located at the cooling

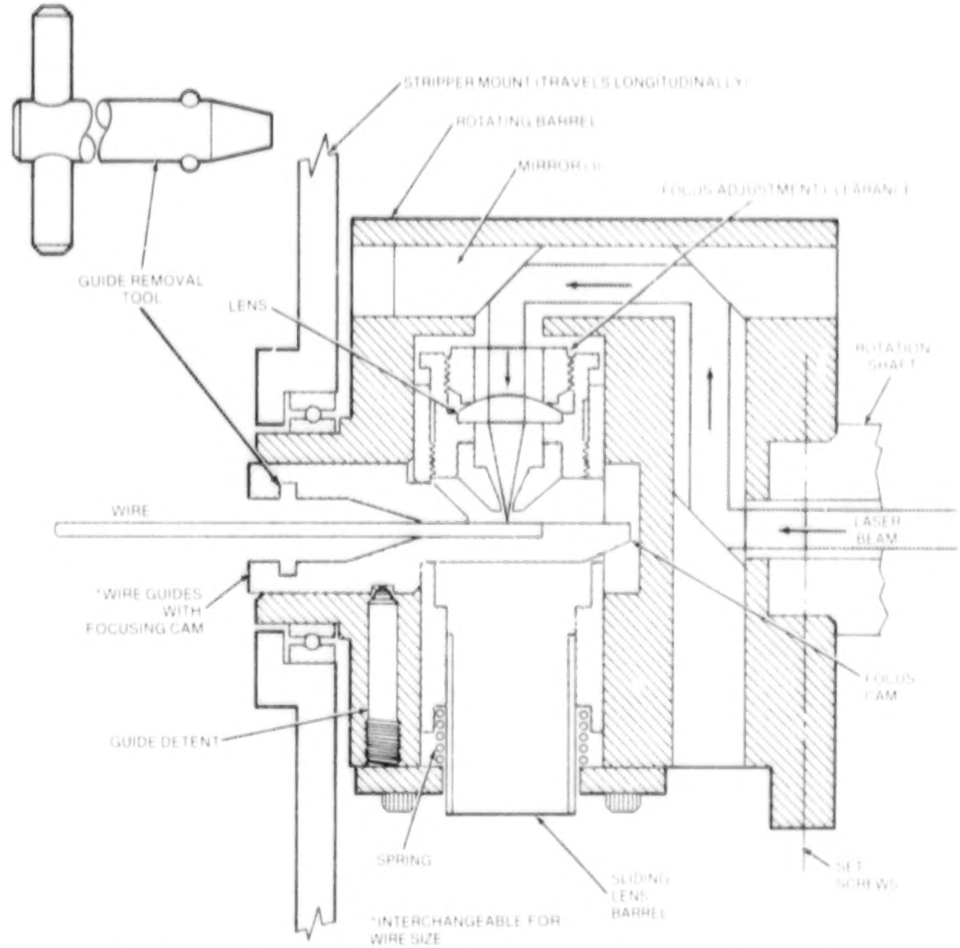


Figure 33. ***Wire guides also position focusing lens*** **in laser wire stripper at the optimum distance for cutting the insulation. Various interchangeable collets are used for holding wire sizes from AWG 26 to 1/0. (MSC-19496)**

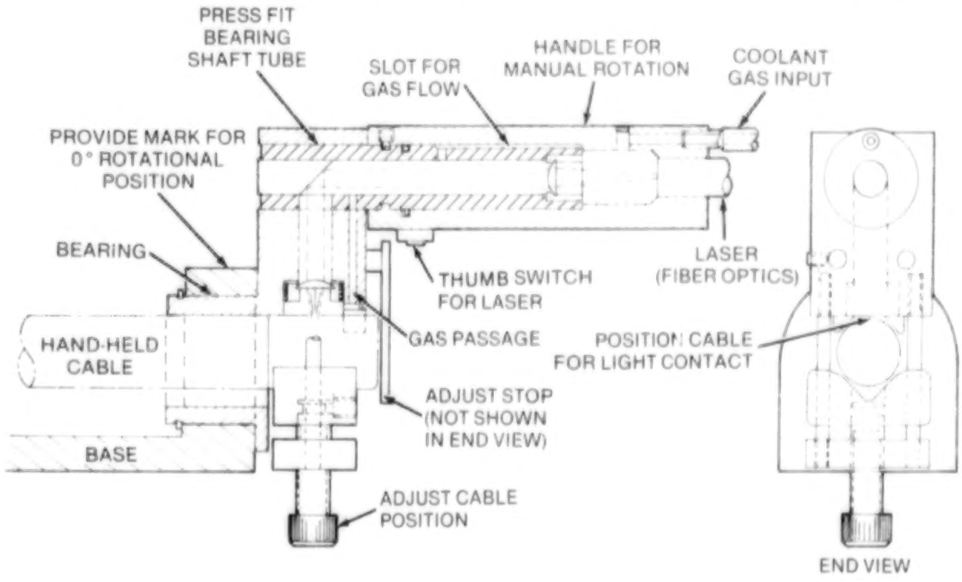


Figure 34. ***Manually-operated rotating optics wire stripper*** **with fiber-optic cable input from Nd:YAG laser permits laser stripping of large cables. Concept only; not built. (MSC-19541)**

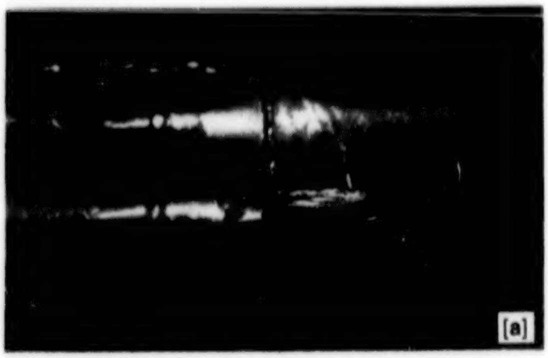


Figure 35. Stripping Large Cables such as this one is difficult and expensive by mechanical techniques. The experimental stripping cuts shown were easily made by manually manipulating the fiber-optics bundle from the Nd:YAG laser to simulate the concept of Figure 34.

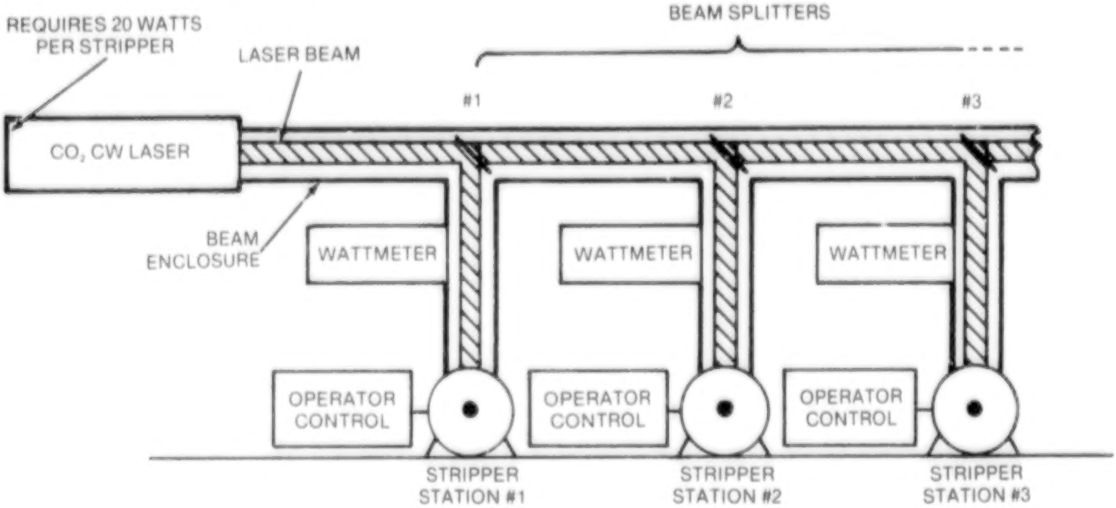


Figure 36. ***Power splitting*** **allows the beam from a single high-power CO_2 laser to supply several bench-mounted stripping units. Each partially reflecting mirror deflects about 3 watts to a stripping station. (MSC-19747)**

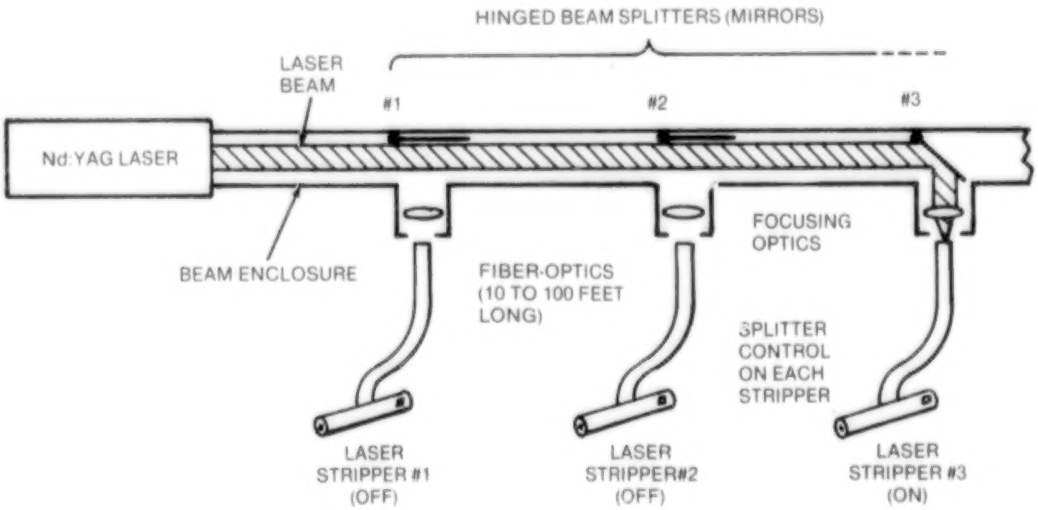


Figure 37. ***Time sharing*** **is another technique for driving many wire strippers from a single laser. It does not require a high-power laser. (MSC-19747)**

unit in the cabinet that houses the power supplies and controls. Laser operation is controlled within a narrower temperature range, so increased average power can be used. The steadier laser output provides more consistent stripping action. This improvement increases the wire-stripping capability for a particular laser unit. Used with the miniaturized CO_2 laser for the hand-held laser wire stripper, it upgraded the output power rating from 1.3 to 2 watts.

Not only does the improved temperature control increase laser output by allowing operation at a higher laser-cavity temperature, but the more tightly controlled temperature range results in a steadier beam with more consistent cutting action. The stripping speed of the hand-held unit can be increased by 25 percent as a result of this innovation.

In Figure 19 the temperature sensor is shown mounted on top of the miniaturized CO_2 laser. The input power lead and the coolant hoses enter at the left in the photograph.

Gas-Jet Pressure Switch (MSC-19573)

A lens-protection system prevents damage or destruction of the focusing lens in the laser wire stripper, either of which might occur due to low pressure in the gas jet. A differential pressure switch senses loss of coolant-gas pressure and automatically closes a lens shutter to prevent lens overheating. This improvement also prevents poor-quality wire-stripping action due to reduced flow of the gas jet.

Gas for the jet is usually supplied from regulated tanks that the operator must check periodically. If low pressure goes unnoticed, the laser lens overheats, becomes coated with debris, and must be replaced, resulting in machine downtime. However, the simple system diagramed in Figure 38 provides automatic protection. If the gas pressure drops below the level necessary for adequate cooling of the lens (about 17 psi in the CO_2 laser wire stripper), the shutter closes.

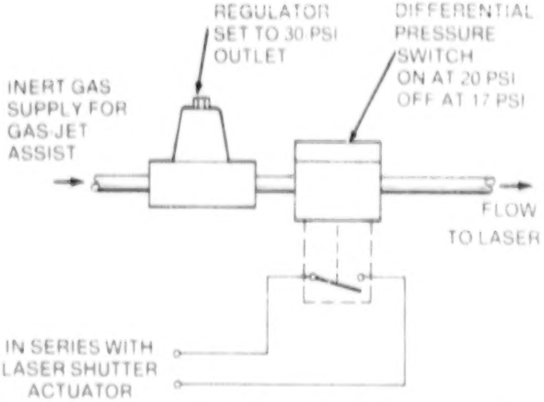


Figure 38. ***Pressure switch*** **in gas-jet line of laser wire stripper is a safety feature. If the pressure is below the prescribed level, the switch cuts off the whole system, thus preventing operation that could damage the focusing lens. (MSC-19573)**

Time-Shared Servocontrol (MSC-19692*)

The rotating optics system in the laser wire stripper incorporates one servocontrolled motor for rotation and another for longitudinal displacement. The two motors operate at different speeds, and therefore two control amplifiers might normally be used to drive them. However, a switching circuit permits time-shared use of just one amplifier to drive the two servocontrol motors at different speeds. The new single-amplifier controller reduces cost, requires less space, and improves reliability.

The system utilizes a series of relays in conjunction with the cam in the laser optic drive to sequentially switch the required potentiometers and the single power supply. This setup first operates the circumferential stripper servomotor, and then switches the connections to supply a different voltage that operates the longitudinal servodrive at its own speed setting. The operator initiates the entire cycle by actuating a single switch.

Wire Types and Cutting Techniques

The laser wire strippers developed by NASA are intended specifically for removing insulation from wire sizes AWG 26 to 1/0. The wire is held still while the stripping head makes one circum-

ferential cut and then one longitudinal cut to the end of the wire. However, several variants upon this procedure have been proposed.

Protection of Stripped Wire End (MSC-16149)

The longitudinal cut is modified so that only a partial cut is made along the insulation slug remaining on the wire end after the peripheral cut is completed, as shown in Figure 39. The protective slug is firmly fixed, yet is easily removable for connecting the wire.

This method is superior to making a complete cut along the side of the slug or omitting the cut altogether. With the complete cut, the slug is too easily detached and wire-end damage is excessive. With no cut, removal is not practical without special tools. The new technique is appreciably less expensive.

By making an incomplete side cut, along the side of the cylinder of insulation that remains attached to the wire end after the girdling cut has been made, the costly problem of damage to unprotected stripped wire ends and/or removal of solid protective slugs is eliminated. Tests show that this type of slug provides an ideal degree of retention during handling to protect the wire end. The slug is also easily removed for final connection of the wire, particularly with new insulations, such as polyimide, that are difficult to grip and have strong bonds to the conductors.

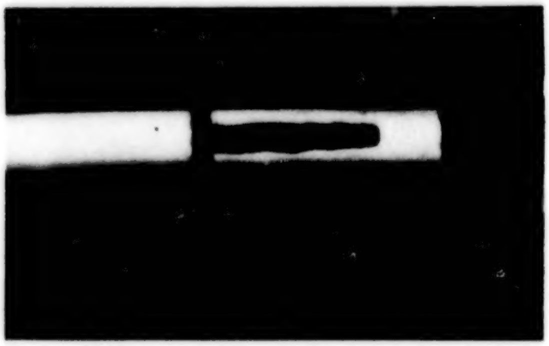


Figure 39. For *protection* of the stripped end of the wire, only a partial lengthwise slit is made along the insulation. The insulation slug therefore stays in place, preventing frayed and/or bent strands, yet is easily removed when no longer wanted. (MSC-16149)

Multiple-Rotation Stripper (MSC-19742)

A simplified design for the rotating optics of the laser wire stripper, utilizing several fast rotations, provides a narrow, clean peripheral cut that permits the slug to be pulled by hand without a longitudinal cut on Kapton-insulated 10-gage or smaller wire.

The repeated-rotation stripping produces a narrower cut for the same beam width, and significantly reduces charring of the conductors and outgassing. As a result, the slug is easier to remove without a longitudinal cut. The stripper drive is a single inexpensive motor, which replaces previously used amplifiers and servocontrols, greatly simplifying the stripper mechanism. A simplified production-type handheld laser wire stripper, giving full assurance against conductor damage and providing rapid stripping action, can be produced for less than half the cost of a hand unit (not including laser) that makes both peripheral and longitudinal cuts in the insulation.

Figure 40 shows the improved peripheral cut on 10-gage aircraft wire with Kapton insulation and a view of another similar wire with the previous peripheral and longitudinal cuts. A small abrasive-grip plier is usually used to remove the slug before assembly to a connector.

Offset Cut for Shielded Cable (MSC-19415)

In laser stripping shielded conductor cables, the laser beam must be offset from the center of the wire to prevent damage to insulation on the inner conductor cables. Figure 41(a) shows the wire braid openings through which the laser beam can penetrate, and Figure 41(b) shows the braid pulled back to reveal minute burn spots (caused by the beam) on the insulation of the inner conductor.

When the wire holder and rotating optics of the laser wire stripper are modified so that the laser beam is properly offset to the edge of the cable outer conductor, it removes the outer insulation jacket with no burn spots on the inner conductor insulation.

Work is continuing on other ways of preventing laser damage to the inner layer of insulation. One pending solution is to have a reflective metallic-coated film wrap under the shield of the coaxial cable. This would be incorporated by the cable manufacturer and would also increase cable shielding.

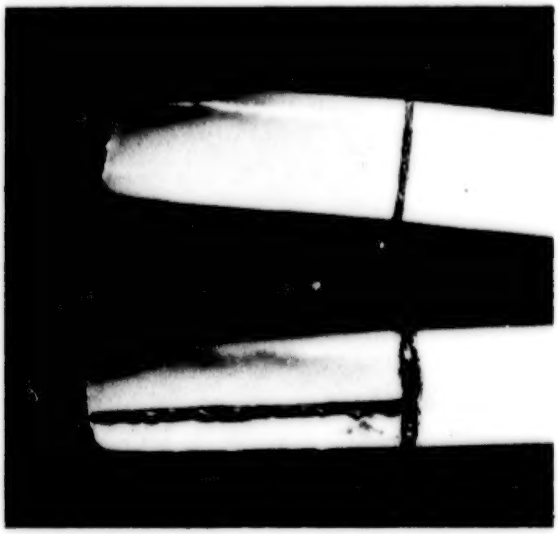
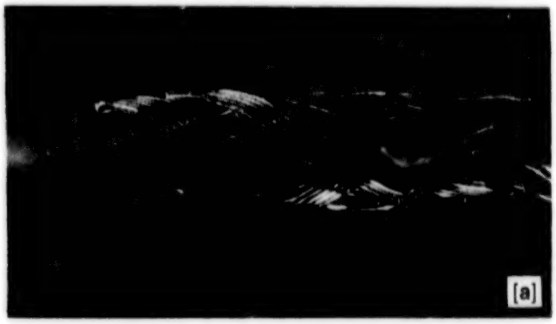


Figure 40. Narrow cut, made by several fast rotations of the laser beam, is seen on the upper wire. The lower wire shows the broader cut that is made by a single slow rotation of the same laser beam. [MSC-19742]



[b]

Figure 41. In shielded cable, the laser beam that cuts the outside insulation can penetrate through openings in the braided outer conductor [a]. The result can be burned spots on the inner insulation [b], unless the laser beam is offset to cut along the side of the cable instead of on top. [MSC-19415]

APPENDIX

Sources

The innovations described in Chapters 3 and 4 were reported as new technology under NASA's Technology Utilization Program. Innovation reference numbers are cited below, along with the Technical Support Packages (when available).

Technical Support Packages may be obtained by contacting the

Technology Utilization Officer
Johnson Space Center
Code: AT3
Houston, TX 77058
(713)483-3809

NASA has decided not to apply for patents on these innovations.

MSC-16149, "Protection of Stripped Wire End" (page 29)
Innovator: William F. Iceland.
No further documentation available.

MSC-19344, "Establishing the Concept" (page 6)
Innovators: Robert M. Heisman, William F. Iceland, Andrew R. Keir, and Floyd R. Yerian.
No further documentation available.

MSC-19369, "Concept for Portable CO_2 Laser With Rotating Optics" (page 23)
Innovators: Robert M. Heisman, William F. Iceland, and Andrew R. Keir.
No further documentation available.

MSC-19415, "Offset Cut for Shielded Cable" (page 29)
Innovators: Robert M. Heisman and William F. Iceland.
No further documentation available.

MSC-19418, "Concept for Portable Nd:YAG Laser with Fiber-Optic Connector" (page 23)
Innovator: William F. Iceland.
No further documentation available.

MSC-19496, "Automatic Focusing of Rotating Optics" (page 25)
Innovators: Andrew R. Keir and Lester A. Small.
No further documentation available.

MSC-19541, "Manual Laser Wire Stripper for Large Cable" (page 25)
Innovators: William F. Iceland and Floyd R. Yerian.
No further documentation available.

MSC-19558, "Improved Temperature Control" (page 25)
Innovators: Robert M. Heisman, William F. Iceland, and Andrew R. Keir.
Further documentation: TSP MSC-19558, "Improved Temperature Control Increases Output of Hand-Held Laser Wire Stripper." Drawings covering the hand-held wire stripper, indicating the method of attaching and wiring the direct temperature sensor.

MSC-19571, "Interchangeable Optics for Different Lasers" (page 25)
Innovator: Andrew R. Keir.
Further documentation: TSP MSC-19571, "Bench Type Laser Wire Stripper with Interchangeable Optics for YAG or CO_2 Lasers." Detail drawings of the unit.

MSC-19573, "Gas-Jet Pressure Switch" (page 28)
Innovators: Robert M. Heisman, William F. Iceland, and Floyd R. Yerian.
No further documentation available.

MSC-19692, "Time-Shared Servocontrol" (page 28)
Innovators: Robert M. Heisman and Floyd R. Yerian.
Further documentation: TSP MSC-19692, "Time-Shared Servo Control Amplifier for Laser Wire Stripper." Schematic diagram of single-shared-amplifier circuit.

MSC-19742, "Multiple-Rotation Stripper" (page 29)
Innovators: Robert M. Heisman and William F. Iceland.
No further documentation available.

MSC-19747, "Multiple Stripping Stations from One Laser" (page 25)
Innovators: Robert M. Heisman and William F. Iceland.
No further documentation available.

MSC-19770, "Nd:YAG Fiber-Optic Hand-Held Laser Wire Stripper" (page 23)
Innovators: Robert M. Heisman and William F. Iceland.
Further documentation: TSP MSC-19770, "Fiber-Optic Type Portable Hand-Held Laser Wire Stripper." Tool drawing (21 sheets) of fiber-optic laser wire stripper.

References

1. R.G. Haas, "Triple Twist Wire Preparation by CO_2 Laser," *IBM Technical Disclosure*, Vol. 13, No. 12, p. 3794, May 1971.
2. P.M. Desautels and H.C. Schick, "High-Energy Arc Wire Insulation Removal Tool," *IBM Technical Disclosure*, Vol. 13, No. 12, p. 3756, May 1971.
3. T. Balmer, "Rotating Optics Direct Wire Stripper," *Design News*, p. 77, May 21, 1973.
4. C.W. Harris et al, "Laser Bent Beam Controlled Dwell Wire Stripper," U.S. Patent 3,953,706, April 27, 1976. A copy of this patent may be obtained from the Commissioner of Patents, U.S. Patent Office, Washington, D.C. 20231, for 50 cents.
5. "Waveguide Laser Finds a Manufacturing Job," *Machine Design*, p. 6, May 19, 1975.
6. Iceland, W.F., "Design and Development of Equipment for Laser Wire Stripping," *Proceedings of the Society of Photo-Optical Instrumentation Engineers' Symposium*, San Diego, California, August 1976.
7. "Lasers Strip Wire Insulation," *Electronics*, p. 52, September 16, 1976.
8. "American Optical Laser Wire Stripper," *Industrial Research*, p. 65, November 1973.
9. R.L. Naney, Bendix Report 613-1067; also N75-10438, "Insulation Removal from Woven-Wire Tape—Chemical and Laser Stripping" ($3.25). This document may be obtained (prepayment required) from the National Technical Information Service, Springfield, Virginia 22151.
10. R.T. Horn, Bendix Report 613-1208; also N75-77779, "Laser Stripping for Wire Breakage Diagnosis" ($4.00). This document may be obtained (prepayment required) from the National Technical Information Service, Springfield, Virginia 22151.

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